SATELLITE MISSION OPERATIONS BEST PRACTICES

ASSEMBLED BY THE

BEST PRACTICES WORKING GROUP
SPACE OPERATIONS AND SUPPORT TECHNICAL COMMITTEE
AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

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DISCLAIMER

The AIAA Space Operations and Support Technical Committee (SOSTC) cannot accept responsibility for any successes or failures that may have resulted from the use of these Best Practices. They are simply recommendations, suggestions, and rules of thumb based on Lessons Learned. In using these Best Practices, please consider how each recommended Best Practice would be implemented in your particular application and determine for yourself whether or not they seem appropriate. (12/26/00)

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FOREWORD

(4/18/03)

The effort of compiling a collection of Best Practices for use in Space Mission Operations was initiated within a subcommittee of the American Institute of Aeronautics and Astronautics (AIAA) Space Operations and Support Technical Committee (SOSTC). The idea was to eventually post a collection of Best Practices on a website so as to make them available to the general Space Operations community. The effort of searching for available Best Practices began in the fall of 1999. As the search progressed, it became apparent that there were not many Best Practices developed that were available to the general community. Therefore, the subcommittee decided to use the SOSTC Annual Workshop on Reducing Space Mission Costs as a forum for developing Best Practices for our purpose of sharing them with a larger audience. A dedicated track at the April 2000 workshop was designed to stimulate discussions on developing such Best Practices and forming working groups made up of experienced people from various organizations to perform the development. These groups were solicited to help outside the workshop to bring this effort to fruition. Since that time, bi-weekly teleconferences have been held to discuss the development of the Best Practices and their posting.

One set of Best Practices that did exist was the result of a NASA Goddard Space Flight Center activity. The Satellite Operations Risk Assessment (SORA) Team produced some Best Practices based on research into a problem with SOHO operations. This set was available to us and we used it as a model. In addition to the SORA report, we started with a list of topics and functions involved in Mission Operations. Members of the Best Practices Working Group volunteered to lead the development of Best Practices for particular topics. We scheduled the telecons such that particular topics were to be discussed on particular days. The leader for that topic would send out the draft of Best Practices to the group via email. This was the basis for discussion during the telecon. Following the telecon, the leader would incorporate the various comments received. The telecons were very informal. Announcements with a proposed agenda were sent out prior to the day of the scheduled telecon (sometimes the day before) and minutes were kept and emailed to the group for those who could not attend (unfortunately not always in a timely manner). Action items were assigned as appropriate. The end results of these discussions are the sections presented within this document.

There are many reasons why this effort has been possible. One in particular was used as a selling point to the development group. First of all, we could! These are simply recommendations and rules of thumb; not declarations of what you “shall do”. These are NOT Standards and would not go through the years of review often required of Standards. This is a way that real experienced people can do something to help their fellow Mission Operations team members and possibly help shape future Mission Operations. It is stressed in the “disclaimer” that these Best Practices are simply recommendations based on Lessons Learned. Many times when we think of our Best Practices, we are looking at things we did right in the past and would do again the next time.

These are Lessons Learned-applied! This is our way of sharing with the community those things we did right so they may be able to take advantage of past experiences.

This effort could be construed as another attempt to foster the "Faster, Better, Cheaper" paradigm in that it may facilitate re-use of proven "processes"; but it was really put forth for another purpose. The underlying objective was to provide someone who has not done this before with some insight into what has worked in the past, and give them guidance as to how they may want to implement their Space Mission Operations related application. It is this underlying principle that forms the basis of the SOSTC Best Practices Working Group (BPWG) logo. In case you have seen it (perhaps it is on the cover page) and don't quite understand: Our "Rookie" Mission Operations Manager is trying to reinvent the wheel. We don't want to see that happen. The BPWG is trying to reduce this type of occurrence by making our Best Practices available to anyone; especially to the "Rookie" Mission Operations Managers!

In closing, there is one main reason why this effort has been as successful as it has been and it must be acknowledged here. It is the time and effort of the people on the BPWG. I was somewhat surprised at the dedication and hard work these folks put in to a "zero budget" effort. It has really made me appreciate what experienced professional people can do if they have a focused goal. My thanks go out to the members of the team who have "suffered" through the "every-other" Friday telecons. My thanks also go out to professional who have provided us feedback. As of April 2003, this effort is ongoing. We are always looking for new members to take on some of the topics we have not touched on. If you are interested in helping out or wish to comment on what we already have, please contact me at:

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Whether you are considered a Ground System Administrator, Spacecraft Operator, Principle Investigator, Program Manager, Chief Scientist or, in particular, a Rookie Mission Operations Manager, we hope you find the information contained within beneficial. Please remember that these are recommendations, suggestions, and rules of thumb. They are not guaranteed to bring you success, but they may help your avoid some trouble.

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Acknowledgment

(04/18/03)

The Space Operations and Support Technical Committee's Best Practices Working Group would like to thank the former group members and reviewers who have graciously and valuably contributed to this effort. Those members are recognized below:

Former Members

Roger Brissenden
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We would also like to thank the members of the Space Operations and Support Technical Committee who reviewed the document and found it to be so good, they didn't need to provide comments. Seriously - thank you for taking the time.

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CONFIGURATION MANAGEMENT FOR SATELLITE OPERATIONS

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April 13, 2001

1.0 <u>Introduction</u>

Configuration Management (CM) is handled in different ways at different levels. From the operations perspective, the goal of CM is to produce reliable results when conducting satellite operations. The real reason for CM is that there is a single point of control that is held responsible for satellite operations.

Configuration Management is the act of controlling all mission-impacting aspects of the satellite operator's environment. CM introduces organizational control into satellite operations. A properly controlled environment will produce predictable results, and allows the Program Manager to assume total ownership and responsibility for program success or failure. In some cases, this ownership may be held by the Operations Manger (OM). A real-life example is listed below:

Operational procedures established the process by which a change to the real time environment was allowed. CM managed the change request, tracking, disposition of the approval authority and audit processes. Once CM approved a change, that change could be made to software/hardware, and made ready for operational use. However, only the Operations Manager could remove/fallback to previous configurations without CM actions. The Operations Manager functioned as an approval authority of one. No one else got a vote. So CM could approve a change, but if the OM had any concern, the change would never reach the operational floor. Change of operational procedures was the domain of the Operations Manager and he delegated this authority to subordinates for execution.

Configuration Management in this definition applies to the use of hardware, software and procedures. Contrast this with the definition of CM given by the newsgroup *comp.software.config-mgmt*:

There are a number of different interpretations. For purposes of this newsgroup, we are talking about tracking and control of software development and its activities. That is, the management of software development projects with respect to issues such as multiple developers working on the same code at the same time, targeting multiple platforms, supporting multiple versions, and controlling the status of code (for example beta test versus real release). Even within that scope there are different schools of thought:

- *Traditional Configuration Management - Checking/checkout control of sources (and sometimes binaries) and the ability to perform builds (or compiles) of the entities. Other functions may be included as well.*

- *Process Management - Control of the software development activities. For example, it might check to ensure that a change request existed and had been approved for fixing and that the associated design, documentation, and review activities have been completed before allowing the code to be "checked in" again.*

While process management and control are necessary for a repeatable, optimized development process, a solid configuration management foundation for that process is essential.

This definition introduces the concepts of Configuration Management, Process Management, Problem Management and Requirements Management. This newsgroup is concerned with software development, but their approach could easily apply to any development process. This CM approach handles the development environment, but does not handle the additional strain of an operational system. Since development and operations are often asked to co-exist, the overall CM process should be defined at the program level, and not controlled by either the operators or the engineers.

2.0 Configuration Management Tools

There are a number of commercially available tools to help simplify the Configuration Management task. They include revision control software, requirement management and tracking software, and others. Don't be fooled into letting a software tool define your process! The CM process is larger than the tools that help carry it out, and hence specific tools are unlikely to be named as an important part of these Best Practices. The application of different tools may provide insights, but the underlying process is more important.

3.0 Best Practices

3.1 *ABSOLUTELY EVERYTHING* Must be Covered Under the CM plan!!! Neglecting seemingly un-important aspects will introduce ambiguity, invites "judgment calls", and creates headaches for everyone. At one time, the CM process at CERES only applied to the core mission software. We eventually realized that configuration scripts, passplans, and even procedures had a great impact on the success of our missions, and we incorporated these areas into our overall CM process. It is easier to start out doing this, rather than trying to get your staff to implement and conform to a more restrictive CM process after significant development has occurred in an uncontrolled environment. If not practical to implement everything under CM, then a careful evaluation must be made of the areas not covered to assess their possible mission impacts. Some form of change control should be followed. For example, for changes to products or databases used in real-time, change authority could be given to the “shift leaders”, or to other lead individuals for other areas.

3.2 Implement a Default CM Process and Leave no Gray Areas. The CERES approach to CM is that any change needs to be covered by a process. A change is anything that changes bits on the hard drive, or any physical configuration. This includes plugging in a network cable, or powering up a workstation. In more complex systems; however, a distributed change authorization process may be necessary in order to make the system manageable. The CERES default process is the Change Request (CR) process. Each CR must be approved by the Requirements Screening Panel before it is worked, and this panel consists of both peer review and organizational buy-in. Now, this is obviously too restrictive to be feasible. The loophole is that anything can be pulled out of the CR process, but only if another *approved* process is created to cover this activity. This still allows leadership to manage the configuration by approving the way things are to be done, but the actual working level has the opportunity to do things the way they want to do it. Examples of things that CERES has put under separate processes are maintenance actions, system administration procedures, orbit analysis procedures, real-time operations procedures and mission planning activities. Remember that most real-time activity results in data being generated or modified on your system, and it is wise to consider what exactly is happening and what the impacts might be.

3.3 Include Procedures in the CM Process. Procedures are developed and approved as a method of controlling how the satellite mission is conducted. Once procedures are put in place, any changes should also be approved at the same level as the initial procedure. Otherwise, the organization loses the ability to accept responsibility for mission success or failure. The program lead can make conscious decisions to delegate approval authority to an appropriate level, but this delegation should be clear and specific. This also includes any products associated with the procedures such as scripted command files, memory loads, and telemetry displays. Date and revision numbers, as well as a history of the changes to the product should be a part of the product itself.

3.4 Document Your CM Process. Having a CM process that is undocumented, and learned through OJT is an easy trap to fall into. This is even truer if you rely heavily on software tools to handle your CM. It is hard to hold people responsible for following the process when it is not clearly spelled out, and this problem is only compounded by personnel turnover. CERES has found that not only are there fewer deviations from the CM policy when it is documented, but the staff is also quicker to learn the process, and more willing to follow it.

3.5 Allow for an Accelerated Path Through the CM Process. It is never acceptable to ignore the CM process in an emergency. If the process does not allow emergency database updates in an anomaly, or quick recoveries from catastrophic system failures, then fix the process, but don't ignore the process thinking it will save you time. This means only including steps, checks, and decision points in your process, which truly are important. The approval authority for each of these steps should be available whenever operations are being conducted, so this means having a documented backup in case the original person cannot be reached. This allows a change to be pushed through out-of-cycle, while reserving all decisions for the appropriate position or level. On the flip side, there are very few, if any at all, changes which must be made immediately. The current configuration has already been tested, approved, and baselined, and if it has worked for the last few months, it will probably continue to work at least as well for the next few hours or days.

3.6 Consider Implementing Audits. Audits ensure that changes, which have been approved, are actually incorporated into the operational environment.

END

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OPERATIONS STAFFING

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April 18, 2003

1.0 Operations Staffing Best Practices

Operational staffing is dependent on several variables including the complexity of the operations; whether or not interactive payload operations are supported; the degree of automation that has evolved, how many spacecraft are supported by a single control center, whether or not the team also controls antenna, and whether all support functions are provided within the control center staff or there are external support organizations.

Because there are so many variables and thus so many ways that responsibilities can be allocated to positions. This section is divided into two subsections. The first subsection describes functional groupings of responsibilities. While these groupings are similar to actual positions on many teams, individuals might perform more than one function, particularly in smaller teams. The names given to these functions vary among organizations; some alternatives are given for some of these descriptions, however this is not intended to be exhaustive. The main use of this section is as a checklist of functions that need to be covered. Ancillary positions, such as administrative assistants, trainers, etc., are not included.

The following section on Staffing Profiles shows the mapping between actual positions and these functions for four examples: a dedicated team, including all payload and engineering support, for a complex mission, a dedicated medium complexity mission team with support from other organizations for payload management and general sustaining engineering, a dedicated team for a simple, highly automated mission, and a team operating several spacecraft. This is not intended to cover all possibilities, but rather to illustrate by example how functional allocation to position can be adjusted to meet mission support needs.

2.0 Functional Descriptions

2.1 Direct Operations Functions

The operations controllers are responsible for real-time interactive spacecraft commanding and data capture activities for assigned spacecraft contacts. The more senior will be responsible for shift briefings and debriefings, maintaining the shift log, and generating management reports. There are three types of operations controllers: spacecraft, payload, and ground system.

Spacecraft Controller: The Spacecraft Controller (SC), sometimes called a spacecraft analyst, is a lead shift console position that directly interacts with the spacecraft and the ground network during real-time supports. The SC performs the pre-pass briefing, may need to direct the ground network's action such as requesting a sweep of the uplink, and participates in the post-pass debrief. Spacecraft Controllers are responsible for implementing the plans provided by the Mission Planning & Scheduling function. The SC monitors "tactical" spacecraft performance, detects spacecraft anomalies, notifies the Spacecraft Operations Engineers of new anomalies, and logs the details of each contact.

At times the SC may implement certain contingency plans, and will routinely implement alternative operations as required. However, the SC does not investigate or resolve undocumented anomalies, they merely detect and report them. The reason for this approach is because the SC's prime purpose is to ensure the safety of the spacecraft, which could be compromised if they are distracted hunting anomalies. Also, the SC is not an expert on the spacecraft subsystems, although he/she has a thorough understanding of how the subsystems work and interact. The SC does not implement any operations without the pre-approval and guidance of the senior authorized staff.

Command Controller: The Command Controller (CC), usually the more junior on-console position, uploads commands to the spacecraft according to contact plans, verifies spacecraft response to these commands, and reports any anomalies to the SC.

Payload Controller: The Payload Controller (PC) is responsible for monitoring the performance of the payload, including science instruments and any instrument support subsystems, during real-time operations. The PC also provides any real-time commanding and control of the payload as needed. For simple missions, this is usually performed by the Spacecraft Controller. On more complex missions, real-time payload control is often performed by a separate payload operations team.

Ground Controller: The Ground Controller (GC), also called a command analyst, is a real-time operations position that is responsible for ensuring the ground system and (if the MOC has direct control of the ground antenna station) network assets are able to support a spacecraft contact and collect, transfer and/or store its data stream. The primary GC function is to monitor (and as the situation requires and authority allows, modify) the GC contact schedule and ensure that the network is properly configured in time to support each scheduled contact. As anomalies occur, the GC is also responsible for real-time troubleshooting and implementing work around procedures to maximize the chances of contact success. Finally, the GC maintains a log of all activities for each contact and notifies engineering support personnel of system outages and problems that may require maintenance or repair.

Mission Planner: The Mission Planner (MP) is responsible for all the products required to operate the mission on a nominal, daily basis. The primary MP functions are: to determine the spacecraft's ground visibility; coordinate with the science planners to select and schedule payload operations; schedule ground contacts; create, verify and transfer command loads to execute these operations and contacts; coordinate with the SOE to plan spacecraft operations and maintenance activities; and build contact plans to guide the SC through each support.

Data Analyst: The Data Analyst (DA) is responsible for managing the mission data flow and processing from the time it is received from the ground station until it is delivered to the customer or archived. Most data management systems are highly automated; therefore the DA's prime responsibility is to monitor the system operations, and to troubleshoot system problems and anomalous data conditions. The DA monitors the data quality ensuring that any corrupted data packets are identified for possible retransmission, that the initial processing is accomplished, that processed data are archived, and that the data are delivered to customers in a timely manner. The real-time monitoring and control of the Data Management function is the responsibility of the Ground Controller. Mission needs for real or near-real time payload data delivery will determine the degree to which the DA involves real-time operations. For most missions it does not. The DA is also responsible for compiling the contact/observation reports based on the planned timeline, console logs, and analyst reports for the "as-happened" events.

Orbit Analyst: The Orbit Analyst (OA) performs the flight dynamics function and is responsible for validating tracking data, creating orbit products, determining and predicting spacecraft position, formulating maneuver plans and verifying the validity of orbital products and processes. Orbit products are provided to the Mission Planner, the Science Planning Team, and to the tracking networks.

Spacecraft Operations Engineer: The Spacecraft Operations Engineer (SOE) is the position with overall responsibility for determining and ensuring spacecraft safety and mission effectiveness. The primary SOE functions are to support prelaunch spacecraft functions, supplement other operational positions as necessary, report spacecraft status to management, and coordinate with spacecraft component manufactures and integrators as required. The SOE also has the responsibility for monitoring the health and status of the payload as it affects the spacecraft bus health and resources, including such engineering data such as temperatures, voltages and currents. The SOE is responsible for the trending and analysis of critical spacecraft SOH parameters and detecting anomalies or potential problems based on both short- and long-term performance trends. The SOE is responsible for identifying, documenting, and resolving spacecraft anomalies that are reported by either the SC or other sources. If the anomaly cannot be resolved by the SOE, then the Anomaly Response Team (ART) can be assembled and employed in the anomaly resolution process.

The SOE can also perform the function of the SC, either as a temporary replacement or to supplement the real-time operations during special activities, such as orbital maneuvers.

Payload Analyst: The Payload Analyst (PA) is the position with overall responsibility for determining and ensuring the payload safety and mission effectiveness. The PA is the equivalent of the SOE, except with responsibility for the payload instead of the spacecraft bus. This role is often provided by a separate payload operations team.

Operations Engineer: The Operations Engineer (OE) is an expert on the operation of the spacecraft and the overall operations architecture. OEs are often the technical lead of the operations team, so this position bridges between operations, engineering support, and management. The OE ideally was involved in the design and development of the operations architecture, and along with the Spacecraft and Payload Analysts, was involved with the spacecraft I&T activities. The OE uses the knowledge gained in system development and I&T to be responsible for developing the operational procedures and handbooks used by the FOT. The OE assists the Spacecraft and Payload Analysts in identifying and resolving anomalies and is responsible for developing, testing and implementing changes in operational procedures, software, or hardware. They direct the efforts of the Software Engineers in developing and testing approved patches or upgrades to both the ground and flight software, based either on their own evaluations or from approved requests from the remainder of the team. They also assist the Systems Engineer in developing and implementing ground system process improvements, including automation.

2.2 Engineering Support Functions

Engineering support staff usually work a standard five-day workweek, but are on call to respond to system problems that threaten operations. Their primary function is to ensure that all infrastructure and system components support the processes put in place by the operations teams to perform readiness and operations. Some of the positions included in this area are the following:

Ground Systems Engineer: The Ground Systems Engineer (GSE) is responsible for the overall integrity and performance of the ground system, including the interfaces between the various subsystems. GSEs monitor the performance of the ground system, collect and analyze performance metrics, perform ground system trouble-shooting, design and implement improvements to operations processes and systems, perform configuration management, and maintain process documentation and on-line information. They will lead the operational testing of any new systems or software. The GSE is also responsible for security issues in network design, such a open vs. closed networks and firewalls. The GSE also is concerned about ground system reliability, maintainability and availability, and might also be the head of the CCB for the ground side of the mission and maintain the DR database.

Flight Software Engineer: The Flight Software Engineer performs software troubleshooting, maintenance, and upgrades as required for the flight software. The work closely with the spacecraft developer engineers, and follow a rigorous verification and configuration control process before any changes are made to the onboard software.

Ground Software Engineer: The Ground Software Engineer performs troubleshooting, maintenance, upgrades, and configuration control for the ground systems software. The GSE may also be required to interface with vendors or other software providers.

Systems/Database Administrators (SDA): The Systems/Database Administrators (SDA) are responsible for all systems management, including Web servers. The SDAs perform all system backups, monitor system performance, and investigate all system failures. They are responsible for receiving and installing new system software patches and set up system login access. They also perform database administration—performing database updates, backups, and restorations as needed. The SDA also implements ground system configuration control.

3.0 Staffing Profiles

The following are provided as examples only. A key way to keep operations costs down is to reduce staff size to the minimum necessary to meet all requirements. The primary risk of minimized staff is lack of depth at key positions, especially for very small teams. One of the mitigation techniques for this risk is cross training to allow people to back each other up. This includes selecting operations management and supervisory staff who can occupy dual positions where they also provide direct operations, at least in a back-up capacity. Although they have the technical skills, the managers take care of personnel issues, ensure the training and proficiency of the people under them, use metrics to monitor performance, and facilitate process improvement. Management and supervisory positions are only described in the staffing profiles section, as they depend on the size of the team.

3.1 Large Dedicated Team

Large, complex missions generally have frequent or lengthy contact with the spacecraft including frequent real-time commanding to respond to dynamic operations scenarios. They usually have 24x7 operations support and relatively complex planning and scheduling processes to support this complexity. The complexity and dynamic quality of their systems also require greater engineering support. This relatively large staff will require one or more managers and an operations supervisor, as described below.

Operations Manager: The Operations Manager (OM) is responsible for all operational personnel and delegates authority through the operational supervisors. This manager must be sufficiently familiar with all operations processes to provide direct supervision of all day-to-day activities, including real-time command and control, mission planning, data analysis, and flight dynamics. However, the normal function of the Operations Manager is to ensure the smooth running and performance of the flight operations teams. The OM interfaces with people outside operations, such as mission and science managers.

Engineering Manager: The Engineering Manager (EM) is responsible for the smooth functioning of the spacecraft and ground segment facilities, including equipment, operations and software. The EM oversees the technicians, engineers, and ground station and testbed operators that are required to perform the maintenance and operations of the space and ground system. The EM's duties include generating purchase requests for equipment and repairs, scheduling and monitoring installations, supervising the maintenance technicians, ensuring remote site security, and maintaining the overall facility support environment.

Flight Operations Supervisor: The Flight Operations Supervisor (FOS), sometimes called a Flight Director, directly supervises all real-time operations and supporting analysis personnel that are directly concerned with the health and operation of the spacecraft and ground network. The FOS will schedule shift operations, and will work closely with operations engineering to improve the end-to-end operations processes. The flight operations supervisor is responsible for the training, certification, and re-certification of the operations personnel. In addition to his/her primary function of coordinating all real-time flight operations processes, the FOS must also be able to assume these real-time and analysis roles as the situation requires.

The following tables show a staffing profile for a typical large mission. Table I shows the nominal mission operations staff. During special circumstances, such as anomaly resolution or initial checkout, additional support will be needed. Table II shows the typical staff for all the supporting services to spacecraft operations. These are maintenance, service, upgrade, and modifications functions necessary for the support of the spacecraft flight operations. These might be dedicated to a mission, or be Full Time Equivalents (FTEs) provided by a larger engineering organization that supports several missions.

Table I – Example Complex Mission Flight Operations Staff

Staff Position	FTE	Shift (Hr/Day)	Comment
Operations Manager	1	8/5	
Flt. Ops. Supervisor	1	8/5	Can also do SC & PC jobs
S/C Controller	4	24/7	12 hrs on, 12 hrs off, 4 days on, 4 days off
Payload Controller	4	24/7	12 hrs on, 12 hrs off, 4 days on, 4 days off
Ground Controller	4	24/7	12 hrs on, 12 hrs off, 4 days on, 4 days off
S/C Operations Engineer	2	8/5	Can also do S/C control and payload analyst
Payload Analyst	1	8/5	Can also do S/C analyst
Mission Planner	2	8/7	Mission Planner and Orbit Analyst share
Data Analyst	2	8/7	
Orbit Analyst	1	8/5	Mission Planner and Orbit Analyst share
Operations Engineer	2	8/5	
Total	24		

Table II – Example Complex Mission Engineering Support Staff

Staff Position	FTE	(Hr/Day)	Comment
Engineering Manager	1	8/5	
Ground Systems Engineer	1	8/5	Fills in for engineering personnel
Systems Engineer	1	8/5	
Technician	1	8/5	Electronic/digital and network
Testbed/Simulator Eng.	2	8/7	Same coverage as the mission planner
Flt. S/W Engineer	1	8/5	Supplemented as needed for upgrades
Ground S/W Engineer	2	8/5	Supplemented as needed for upgrades
System/Database Admin.	1	8/5	
Total	10		

3.2 Medium Complexity Mission with External Support

This case is similar to the first, except that payload support is provided by a separate organization, and flight and ground sustaining is provided by a shared pool of engineers, who also support other mission teams. As shown in Table III, everyone on the operations team reports to an operations manager, and there are separate leads or supervisors for the people who provide routine operations and those providing operations engineering of the spacecraft and ground systems

Table III – Example Medium Complexity Mission Flight Operations Staff

Staff Position	FTE	Shift (Hr/Day)	Comment
Operations Manager	1	8/5	
Flt. Ops. Supervisor	1	8/5	Can also do SC job
S/C Controller	4	24/7	12 hrs on, 12 hrs off, 4 days on, 4 days off
Ground Controller	4	24/7	12 hrs on, 12 hrs off, 4 days on, 4 days off
Mission Planner	2	8/7	Mission Planner and Orbit Analyst share
Data Analyst	2	8/7	
Orbit Analyst	1	8/5	Mission Planner and Orbit Analyst share
Lead Operations Engineer	1	8/5	
S/C Operations Engineer	2	8/5	Can also do S/C control and payload analyst
GS Operations Engr./System Admin	1	8/5	Can also do DA job
Total	19		

3.3 Small, Highly Automated Team

As teams become smaller, the operations positions are increasingly consolidated into a few people, while the functions continue to be performed, though usually in a less complex way. Furthermore, simpler missions are easier to automate, leading to still smaller staff. A primary issue for small teams is retaining knowledge to deal with non-routine circumstances which require deeper understanding of how the spacecraft and operations processes work, and which will also be outside the range of automation. Thus small teams will depend increasingly on operations engineers, the most senior technical members of a team, to be available to support the mission.

Very small teams will typically be staffed 8x5 or 8x7 only. They will have two or three operations controllers who can support all aspects of pass operations, and can also perform routine mission planning and scheduling. If there are few contacts and/or they are automated, these staff members will also assist with data management and routine spacecraft trending and analysis. There needs to be at least 2 OEs, one of whom is the overall mission lead. If there are only two, there should be a knowledge capture and training program for building future OEs. This is to protect against the loss of essential knowledge and skills should one of them leave.

Engineering support is usually obtained from external organizations for small missions, which do not usually have budget for dedicated engineering support teams. Spacecraft engineering often is provided by the manufacturer. Ground systems software sustaining is often contracted to the original vendors. It is wise, however, to have at least one person, possibly one of the OEs but often an addition person who is especially focused on ground systems, on the team who can provide immediate trouble shooting of ground system problems.

3.4 Multi-mission Team

Multi-mission control centers provide small missions a means of retaining greater depth and specialization that is available to larger missions. They also provide some protection from the loss of skills with the departure of key individuals. However, knowledge capture and training is very important for this type of team. A few differences in staffing from a single mission center are described. See the section on multi-mission operations for more detail.

Depending on the number and complexity of the missions supported, the operations staff profile might be similar to that of a large complex mission: two or more people on console on shifts covering 24x7 operations, and various analysts and engineering support on an 8x5 schedule.

The difference from a single large mission comes from the need to allocate resources among several missions, while retaining attention on the needs of each mission individually. This can result in a slightly different management structure. The Operations Manager (OM) will focus on consistent quality of support across all missions and may devote more attention to interactions with multiple customers. The Flight Operations Supervisor (FOS) might devote more attention to schedule conflict resolution. There also should be a lead for each mission, to assure that each mission's needs are adequately addressed, especially when special circumstances require additional support. This should be one of the OEs, who might be designated the Mission Lead Engineer (MLE). For complex missions, one MLE may be dedicated to a mission. For less complex missions, a single MLE may be responsible for two or more missions. For the assigned mission(s), the MLE will provide direction to the off-line and on-line engineering staff, lead spacecraft anomaly resolution teams, and be responsible for the integrity of the mission databases. The MLE will be the primary technical point of contact for the mission customer, working with the customer in such areas as anomaly resolution, changes in requirements or operations processes, and conflict resolution decisions.

END

SATELLITE MISSION OPERATIONS BEST PRACTICES
BEST PRACTICES WORKING GROUP
AIAA SPACE OPERATIONS AND SUPPORT TECHNICAL COMMITTEE

****

SHIFT SCHEDULING WHITE PAPER

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1.0 Introduction

Human physiology has shown us that the body operates in daily, monthly, and yearly cycles. The majority of humans have a daily cycle that includes about 8 hours of sleep, as well as periods of high alertness, drowsiness, and hunger. Some people are more alert during the morning, some people do their best work late at night. It is important for operations managers to recognize the individual differences in their teams and understand the risks inherent in implementing various shift scheduling philosophies.

2.0 Science Versus Commercial Communications

The type of mission and the phase of the mission dictates how operations teams are scheduled. Launch and on-orbit checkout phases invariably require much greater levels of staffing than later, operational phases of all spacecraft missions.

During launch and on-orbit checkout, the risk of malfunction is high, and it is always prudent to have as many experts as possible on hand to work contingencies. After the spacecraft is placed in the proper orbit, and all systems have been verified, staffing schedules can be reduced to satisfy the requirements of the mission.

The nature of commercial communications satellites and their degree of onboard autonomy, for example, require 24 hours per day, 7 days per week (24x7) operations. Anomalies must be recognized and corrected quickly in order to assure that data, telephone, and television links are impacted the least amount possible. Slow reaction to problems resulting in loss of service to paying customers usually incurs large monetary penalties to the operator.

Many science missions, on the other hand, use the “lights out” approach to staffing. The term “lights out” comes from the practice of only requiring a human presence a few hours per day or week, or during contingency operations. When not staffed, the control room is empty and the lights are turned off. The ground systems are automated to the point that data is collected and stored automatically. When anomalies occur, the system will automatically notify by email or pager the on-call individual. Some systems even attempt to notify secondary individuals if the first call is not responded to within a certain time period.

Science missions may be more forgiving to spacecraft downtime if observing sessions can be rescheduled.

Setting up a schedule should also take into account training requirements. Training may take place during normal work hours only. In such a case the staffing levels will have to allow pulling people out from their rotation or team in order to attend training classes.

3.0 Resources and Studies

The good news for spacecraft operators is that many industries use 24/7 staffing to maximize production. Hence much research has been conducted into the effects of round the clock staffing. There is a wealth of information available on the internet on different schemes, rotations, fatigue, and risk factors. A quick search will also reveal several consulting firms who will provide expertise on shift work, state and federal regulations, and health and safety considerations.

It may be interesting to note that some employers who use 24/7 staffing have been found liable for damages when their workers are injured away from the workplace. The employer were found to have not properly educated their employees on the effects of shift work, and failed to provide adequate training in countermeasures.

According to the 2002 Shiftwork Practices Survey published by Circadian Technologies, Inc., "Scheduling practices in manufacturing, industrial process, and utilities operations are highly variable across industries, regions and workforces." Overall, 56% of facilities work 12 hours shifts and 67% have rotating shifts, but this varies widely from one industry to the next, and even from one geographic area to the next. The Survey also noted that "the most popular 8 hour schedules are those that are fixed (47%) or rotate in a forward (days-evening-nights) direction (32%). The most popular 12 hour schedules are the 2-3-2, every-other-weekend-off schedule (44%), or schedules with long 7 or 8 day breaks each month.

"Among companies with 12 hour schedules, 83% work rotating shifts and only 17% have fixed shifts. The highest worker fatigue levels are associated with schedules that rotate on a bi-weekly basis. As well, employers with bi-weekly rotating schedules report the highest rate of accidents and injuries on the night shift."

Studies have also shown that facilities with backward rotating (night-evening-day) schedules "will almost certainly have higher accident rates, employee health problems, and production errors than those facilities with forward rotating schedules."

Although these figures are for the most part from industries other than satellite operators, there are many common factors that can have a direct correspondence to satellite operations. For example fatigue can impair judgment and lead to improper decisions being made. Higher absenteeism and turnover are also problems that affect all shiftwork companies.

There are move than 1000 basic 8 and 12 hour schedules, and countless variations of rotation patterns. The abundance of different schemes is a sure indication that there is no one "perfect" schedule. Experts agree, however, that selection of a schedule should be done with the full participation of the crews involved, and may even include trial periods to allow the teams to evaluate difference schedules.

The table below shows some pros and cons for the various types of schedules. It is by no means complete.

Type of schedule	Pros	Cons
Fixed	Less fatigue. Less risk of error. Workers have stable schedule	Requires more personnel. Hard to find people who will work nights.
Rotating	Less personnel required. Allows personnel to not work constant night shift	Unstable worker schedules. Higher risk and fatigue levels after rotation.
12 hour shifts	Easier to set up schedule. Require less personnel	Longer shifts increase fatigue, risk. May require flexible payroll dept (pay periods may not be consistent)
8 hour shifts	Less fatigue, risk.	Require more personnel to cover 24x7 operations.

4.0 Examples

In this section are some examples of schedules that are used by commercial and military satellite operators. The first three examples use four teams. Example 4 uses 5 teams to fill out a year long schedule.

Example 1

Team	Sat	Sun	Mon	Tue	Wed	Thu	Fri
A	D	D	D	D			
B	M	M	M	M			
C					D	D	D
D					M	M	M
A		D	D	D	D		
B		M	M	M	M		
C	D					D	D
D	M					M	M
A			D	D	D	D	
B			M	M	M	M	
C	D	D					D
D	M	M					M
A				D	D	D	D
B				M	M	M	M
C	D	D	D				
D	M	M	M				
A					M	M	M
B					D	D	D
C	M	M	M	M			
D	D	D	D	D			
A	M					M	M
B	D					D	D
C		M	M	M	M		
D		D	D	D	D		
A	M	M					M
B	D	D					D
C			M	M	M	M	
D			D	D	D	D	
A	M	M	M				
B	D	D	D				
C				M	M	M	M
D				D	D	D	D

Example 1 shows 4 days on, 4 days off, 12 hour per day. Teams work 4 weeks on a shift, then work the opposite shift for 4 weeks. There is a consensus among the discussion groups dedicated to shiftwork that there should never be more than 4 12 hour shifts in a row.

Example 2

Team	Sat	Sun	Mon	Tue	Wed	Thu	Fri
A	D	D	D				D
B	M	M	M				M
C				D	D	D	
D				M	M	M	
A	D	D				D	D
B	M	M				M	M
C			D	D	D		
D			M	M	M		
A	D				D	D	D
B	M				M	M	M
C		D	D	D			
D		M	M	M			
A				D	D	D	
B				M	M	M	
C	D	D	D				D
D	M	M	M				M
A			D	D	D		
B			M	M	M		
C	D	D				D	D
D	M	M				M	M
A		D	D	D			
B		M	M	M			
C	D				D	D	D
D	M				M	M	M

In example 2, teams work 3 days on, 3 days off, 12 hour per day. Teams switch to the opposite shift after 6 weeks.

Example 3

Team	Sat	Sun	Mon	Tue	Wed	Thu	Fri
A			D	D	D	D	D
B	D	D	S	S			
C	M	M				S	S
D			M	M	M	M	M

Example 3 shows a rotating shift. Days that show 3 teams working are 8 hour shifts. Days with only two teams working are 12 hour shifts. From a risk factor perspective, this type of schedule presents the added danger of constantly disturbing the circadian rhythms of the teams, thus increasing the potential for fatigue induced error.

Example 4

Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C
SWINGS	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B
GRAVES	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A
Feb	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28			
DAYS	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B			
SWINGS	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A			
GRAVES	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E			
Mar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E
SWINGS	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D
GRAVES	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C
Apr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
DAYS	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	
SWINGS	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	
GRAVES	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	
May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A
SWINGS	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E
GRAVES	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D
Jun	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
DAYS	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	
SWINGS	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	
GRAVES	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	
Jul	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A
SWINGS	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E
GRAVES	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D
Aug	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B
SWINGS	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A
GRAVES	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E
Sep	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
DAYS	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	
SWINGS	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	
GRAVES	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	
Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B
SWINGS	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A
GRAVES	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E
Nov	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
DAYS	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	
SWINGS	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	
GRAVES	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	
Dec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAYS	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C
SWINGS	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B
GRAVES	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A	A	B	B	C	C	D	D	E	E	A

In Example 4, 5 teams are used. Each team works 6 days in a row, 2 days each of day, swing, and graveyard shifts. After the last graveyard shift, the team has 4 days off.

There are several considerations one must make when thinking about scheduling a 24/7/365 workforce. You must consider costs, quality of life issues, and the interpersonal relationships to build a strong organization. The remaining paragraphs are a case study in shift scheduling used by the US Navy.

There is a shift-scheduling scheme that is currently practiced by the U. S. Naval Satellite Operations Center (NAVSOC) to capitalize on functional teams in a multi-mission SOC. The shifts that are described below are manned by Duty Satellite Managers – or Satellite Controllers. Spacecraft Engineering support, and ground system support personnel work normal business hours, and are "on-call" as the need arises. The type of scheduling NAVSOC employs allows the use of DSMs for training, mission planning, operational support during periods of high activity, as well as various administrative tasks. Though the total shift work strength is 20 to 22 people (cost intensive), the focus is to reduce costs and provide the best quality product possible, especially during periods of high activity. NAVSOC maintains several remote sites that are manned during their normal working hours, so the information given here is from the headquarters perspective.

Once a person has reached full qualification (known as a DSM –Duty Satellite Manager, the process of becoming one is a paper in itself) he/she is assigned to one of five shifts. The shifts rotate forward in time every 8 weeks. The 8-week time period was chosen to give plenty of time for physiological adjustment for the people working the shifts. There are 3 eight-hour shifts during the week, and 2 twelve-hour shifts to cover the weekend shifts (12 on – 12 off). See the table below.

Example 5

Shift Name	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Mids		0030-0900	0030-0900	0030-0900	0030-0900	0030-0900	
Days		0830-1700	0830-1700	0830-1700	0830-1700	0830-1700	
Eves		1630-0100	1630-0100	1630-0100	1630-0100	1630-0100	
WE Mids	0030-1300	0830-1630	0830-1630				0030-1300
WE Days	1230-0100		0830-1630	0830-1630 (Mission Planners)		0830-1630 (Mission Planners)	1230-0100

In Example 5 the table is read from left to right. The Mid ("the Grinder"), Day, and Eve shifts all work eight hour shifts and are assigned primarily to on-shift operations, realtime scheduling and realtime ground system troubleshooting as required. The people on these shifts usually have collateral projects that are worked on during any downtimes, and are "shelved" during anomalies, realtime operations, etc. The day shift is used for the "commanding day", which means all engineering support is present to assist in performing realtime operations to maintain satellite health. A majority of commanding is performed during normal business hours. All shifts are scheduled for an additional 30 minutes at the end of their shift for shift turnover ("passdown"), and are paid overtime for this, as they do not get a scheduled lunch break.

The weekend shifts work 25 hours on the weekend and 16 hours during the week to make a 40-hour week (one hour total of overtime). There are usually 5 – 6 people assigned to both weekend shifts (minimum 2 per shift). The weekend workers are assigned to the day shift for 2 days during the "normal" workweek to perform mission-planning, assist the Day shift in commanding during realtime operations, attend training classes and perform various administrative duties as assigned.

These hours have been in place for approximately a decade, and have been better managed in the last several years to capitalize on the abilities of the weekend shift "day-worker hours.

Shift workers normally stay with the same people throughout the year, which has its benefits as well as drawbacks. It is beneficial when shift teams work so long together that there is a fluid process of getting things done, as well as an expectation for each to shoulder a certain amount of the workload. There is not always a need to actually tell one another what tasks they will perform, they just do it, and do it in a way that is acceptable for all on the shift. However the drawbacks are that, in some cases "familiarity breeds contempt". This is a natural occurrence and sometimes one person on the shift requests a swap with a person on another shift. Yet, from an organizational perspective, it is not always feasible or healthy for people to remain together through the shifts "for life". "Clicks" develop and the opposing shifts do not work to help one another out, but rather only to make themselves to "look good" at the expense of other shifts. The best defense against this is to have a mechanism to where people are split up at certain intervals. This ensures that all of your people can work together as a team. Initially, you will sense that entire organization will be in conflict as people get used to working with a new set of coworkers. However the long-term payoff is that people will become accustomed to change, and that interpersonal fluidity can grow across all personnel. One method that is used at NAVSOC is when people rotate into the Weekend Day Shift to perform Mission Planning. When rotation occurs, one person who performed Mission Planning during the previous two months stays behind, as the new shift people rotate in. Then the shift worker who stays behind in Mission Planning will then train the new Mission Planner. At the next rotation, that Mission Planner will stay behind and a new one will rotate in, and so on. This is only an example of how tasks can be split reducing costs, as well as strengthening the overall interpersonal compatibility of the workforce.

Certainly, having a good quality of life is important not only to the employee, but also to the organization. High turnover is not optimal, since training costs are driven up while the corporate knowledge and expertise nosedives. In addition, absenteeism, as a result of shift work induced sickness is not healthy for an organization. A steady, physiologically healthy shift-scheduling scheme should be achieved to maintain a healthy employee, so in turn a healthy organization can be maintained. The shifts that most people commonly complain about are the Mid Shift (8.5 hour shift 5 days a week) and the Weekend Mid Shift (12.5 hour shift). Most notably on both shifts, heavy fatigue sets in on both of these shifts around 4 am. This is the time when the body is looking to sink into its deepest point of rest.

A side note to mention here is that SWAT Teams and Special Operations units usually train for weeks during the early morning hours in preparation to conduct raids during these hours (1 am to 4 am). They become acclimatized to these work hours to be at the peak of alertness during those hours. They do this because they know their adversary's bodies are trying to "sink" into their deepest point of rest as well, and are not preparing for "work" during these hours.

This early morning period is one of vulnerability to those adversaries' as well as a satellite operations team. The fatigue these two shifts cause can produce the majority of personnel errors that are experienced during satellite operations. Undoubtedly, it is unnatural to work these hours, not to mention maintain a high level of attention to detail – which is required while performing satellite operations. When a Mid Shift worker nears the end of the rotation (end of their eight weeks on mid shift), most comment on how they cannot wait to rotate to the next shift. It is an arduous shift, surprisingly more so than the Weekend Mid Shift. The tradeoff for the weekend worker on the Weekend Mid Shift, is that at the end of their week, they have 3 days off to look forward to (a psychological "lift"). During the week they also are able to sleep normally after a normal workday. This break allows the body to recover somewhat in the short term. The Mid Shift during the week does not allow the physiological reprieve the Weekend Mid Shift allows. An alternative could be to move the shifts back or forward several hours, but in short, there is no easy answer for the person who must work during the 1 to 4 am hours. As an organization it would definitely not be prudent to have a shift ending at 4 am. You would certainly not want your employee to be driving after a shift during that time.

We have explored different shifts and scheduling schemes, to cover satellite operations around the clock. Most organizations will agree that the optimal situation to have is to have a lights out system that employs some sort of pager system when problems are experienced. Yet in this dynamic world of satellite operations, this is not always affordable or feasible. There exists a push for employing COTS equipment. In addition, there exists the competitiveness to employ additional satellite systems to increase services to customers. These dynamics sometimes push the cost of "smart systems" out of budgetary reach of an organization, especially in the post 9-11 world. Yet it is an unavoidable dilemma: Do you minimize your employee base by spending a lot of money on the front end – employing "smart" space and ground systems? Or, do you buy the "budget" space and ground system and spend a lot of money employing smart people to maintain that budget system? Those questions are best answered by the organization and the concept of operations it employs.

These examples are just a fraction of the possible permutations. However, they are being used by commercial, scientific, and military organizations to meet their needs.

SATELLITE MISSION OPERATIONS BEST PRACTICES
BEST PRACTICES WORKING GROUP
AIAA SPACE OPERATIONS AND SUPPORT TECHNICAL COMMITTEE

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TRAINING AND CERTIFICATION

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1.0 Introduction

A training program should have two purposes. One is to shape the culture, or behavior, of the Flight Operations Team (FOT) as it interacts with internal and external interfaces. The second is to teach the FOT how to operate the ground and flight systems. Training that encompasses both of these concepts will help ensure mission success.

In training, one of the most important concepts to remember is "Train as you fly, fly as you train." In other words, define your operations culture early. Then develop a training plan that best creates that culture. Follow through by operating the satellite in the same manner as you have trained.

2.0 Training Goals

The ultimate goal of a training program is to reduce Personnel Errors (Pes). To achieve this goal some basic principles should be kept in mind.

2.1 A Mission Operations Control Center is a unique environment, and the training program should include teaching behavior patterns that ensure effective behavior in that environment. A training program that includes this concept will ensure consistent behavior among the members of the FOT.

2.2 The key to proficiency in any activity is practice and more practice. Simulations and rehearsals of routine and contingency operations prepare the team members for all situations and lessen the chance of Pes during real-time activities.

2.3 Many of the systems used for satellite control are unique to the mission, and often require specialized instruction and practice to make the members of the FOT proficient.

3.0 General Training Program Requirements

This list is by no means definitive, but the members of the SOSTC Best Practices Working Group have found these requirements very useful in setting up a training program.

3.1 Develop a Training Plan. A poorly planned training program will be reflected in the team members that come out of it. Have an experienced FOT member write it or work closely with the training personnel. At the very least, thoroughly review it before release. Include clear goals, expected results, and schedules for completion.

3.2 Develop a Skills/Knowledge Description for Each Position. This should be done in as much detail as possible, along with initial and recurrent training, and certification requirements. Such details make it easier to judge if the trainee has met the requirements, and helps the trainee to understand what goals to strive for.

3.3 Review and Update Training Plans Periodically. This will ensure relevancy with current mission requirements. If the operations have developed in a different direction than anticipated, be sure the training plan also evolves with it. Ensure that the FOT is involved in all reviews.

3.4 Maintain Complete and Accurate Training and Certification Records. This should be done for each individual, and make them easily accessible to both trainer and trainee.

3.5 Staffing Levels Should be Adequate. This is necessary to allow some team members to be in training so that attrition does not leave operations understaffed and at risk. Also rotate FOT members into trainer positions to ensure distribution of the knowledge base. This will provide breaks from continuous console work and reinforce knowledge that is not used frequently.

3.6 Training Should be in the Form of Computer Based Training (CBT). This training should include training material, lessons, and self-tests. The training software should reside in a central server for ease of maintenance and to ensure that only the latest, approved version is used for training.

3.7 Training Modules or Sections. These should focus, as much as possible, on simple skills. Once the simple skills are learned, they can be combined into more complex activities.

3.8 Involve FOT Members. This is important for the success of spacecraft and ground system Integration and Test (I&T) processes. This not only provides good training in system idiosyncrasies that may not be adequately documented by the design team, but also helps to promote an operations oriented point of view during the I&T process.

3.9 Ensure that Design/Testing Knowledge is Documented. This documentation should be passed on to FOT. This can be accomplished by involving, as much as possible, key members of the FOT early in the design and testing process.

3.10 Develop Rehearsals/Simulations. Anomaly/Contingency scenarios are essential in preparing the FOT to handle emergency situations. Each crew should experience these and conduct "crew reviews" (peer reviews) of their actions and possible consequences. These should exercise both nominal and contingency operations. This will provide excellent feedback for procedure development, and help desensitize the FOT to emergency situations and reduce panic responses. Even fatal, non-recoverable scenarios can be useful in this regard. Multiple rehearsals allow for repetitive training as well as specific focused events. Rehearsals can include: Communications rehearsals between the launch center, the operations center, and the factory; Launch and deployment rehearsals; and Day-in-the-Life rehearsals.

4.0 Initial Training

4.1 Identify mission requirements and develop training modules to address them.

4.2 Train and certify the FOT before launch. Orbit raising and in-orbit test should not be a period for training of the FOT.

4.3 Train core skills first, then cross train. Ensure that a complete FOT is prepared to fly the mission, then cross train members.

4.4 Ensure that new hires have basic space operations training as well as mission specific training. This will ensure a common knowledge set for the FOT.

5.0 Crew Resource Management

All air carriers have trained their flight crews in Crew Resource Management (CRM) skills since it was shown in the 1980's that it reduces Pes. It has also been shown to be effective in nuclear power control rooms and medical operating theaters. Satellite controllers work in a similar, real time environment, and the following skills, if practiced by the FOT, will help reduce Pes.

5.1 Leadership/Followership and Teamwork. Knowing how to lead and follow are important parts of teamwork. Leaders must know how to distribute tasks, keep track of the overall situation, and direct the team's attention as needed. Just as important, leaders must listen to their team members and utilize their expertise and talents. Followers must be able to react to their leader's direction, but also know how to help the team leader choose the correct path.

5.2 Communications. Many Pes can be related to poor communications. The use of standard terminology lessens the risk of misunderstanding in both internal and external interfaces. Failure to initiate communications has also been shown to a significant factor in many incidents.

5.3 Situational Awareness. Simply put, knowing what's going on and when it's going to happen. Situational awareness is especially important when the FOT is focused on a problem, and other problems go unnoticed until its too late.

5.4 Task Prioritization. Mission management should establish clear priorities of tasks to help the real time controllers manage their workload during normal operations and especially during contingency operations.

5.5 Event Logging. Keeping an accurate and timely log of events is invaluable in not only tracking the day's activities, but also reconstructing those activities and actions of the FOT weeks or months later.

5.6 Workload Management. Task overload can occur quickly during contingencies. Not only must the team leader be aware of the distribution of workload, but individual team members must be able to recognize overload and ask for help.

6.0 Resources

There are many resources available to help train the FOT. Each member of the team as well the managers should regard everything as an opportunity to learn more about the systems on which they will work.

6.1 Vehicle Assembly, Integration and Test. One of the best ways to ensure that system idiosyncrasies are passed on to the operations team is to get the FOT involved with assembly, integration and testing of the satellite

6.2 Manuals, Specifications, and "As Built" Documents. After ensuring that the "as built" documentation and manuals are as accurate as possible, these may be the only reference source once the vehicle is launched.

6.3 Lectures and Classes. These will provide a good basis of knowledge, and help the FOT to begin working as a team.

6.4 Simulators and/or Rehearsals. These are the only way to practice nominal and contingency operations, and to refine procedures, without risk to flight hardware. They also build teamwork and help desensitize the team to contingencies.

6.5 Mentors and On-The-Job-Training (OJT). No matter how well trained by manuals and rehearsals, new team members should be assigned a mentor who will show them the ropes, help integrate them into the team, and evaluate progress.

6.6 On-going Operations. Visiting existing satellite operations centers prepares the FOT for the operational environment and provides insight into actual satellite operations and operational paradigms.

7.0 Recurrent Training

Training should be considered an ongoing process. Recurrent training should be based on frequency of performance and criticality of performance of the activity. Activities that are performed on a routine basis are continually reinforced and do not require the same amount of training, as do activities that are seldom performed. Recurrent training should be developed with the following points in mind.

7.1 FOT Membership. This will change through attrition, promotion, and transfers.

7.2 Team Members. They should be cross-trained in other positions.

7.3 New Technology, New Procedures, and New Systems. These require that the FOT be familiar with them.

7.4 Routine Procedures. Those that are not used frequently should be trained on a regular basis.

7.5 Critical and Contingency Procedures. These should be trained on a routine and continual basis to insure the desired response by the FOT.

8.0 Certification

Certifying an individual to perform the functions of a given position means that the individual can do those tasks without direct supervision. Requiring re-certification to work in a position helps ensure that the individual is fully capable to perform those functions, and helps motivate the individual to stay current. Levels of certification also motivate and encourage continued growth in the knowledge of satellite and ground capabilities and characteristics.

8.1 Define the level of knowledge required for each position.

8.2 Decide the time period of certification: semiannually, annually, etc.

8.3 Develop computer-based self-tests for personnel.

8.4 Evaluation should be by the team leader/supervisor as well as the training officer.

END

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PROCESS IMPROVEMENT

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1.0 Introduction

A famous general (attributed to Prussian Field Marshall Helmuth von Moltke) once said “No plan survives first contact with the enemy”. This is also true for spacecraft operations. Even the most carefully planned mission operations or support plan will not survive first contact with reality. If the mission operations system has not been designed with the flexibility and built-in processes to recognize problems or anomalies, analyze them, and provide a feedback loop to introduce improvements back into the mission operations process, then it will be very difficult and costly for the system to adapt. It is far better and cost effective to design these process improvement features into the system than to try re-engineering the system after launch. There are many case histories where this is true. Several missions, including the Hubble Space Telescope, have attempted to introduce automation and process improvements into the system after launch, and have had a very difficult time doing so. It is difficult to do this without disrupting or risking the ongoing operations, and when it is possible, it is usually very costly. The golden rule of process improvement is: design the process of process improvement into the system from the very beginning so that it will appear in the design requirements.

This section will look at some means that can be used for helping with the mission operations process improvement, from the determination of suitable metrics, methods to collect and analyze them, determine solutions, and then feed the solutions back into the system. Although the actual metrics and methods that are best suited for a particular mission might be different, the general principles stated herein are the results of experience obtained on several missions, including Low-Power Atmospheric Compensation Experiment (LACE), Clementine, MSTI-3, and others.

2.0 Defining and Using Measure of Effectiveness as Metrics for Process Improvement

A major factor in the cost of spacecraft ground support is the effectiveness of the mission operations process. An ineffective, error-prone and labor intensive process will most likely result in increased cost, risk, and reduced customer satisfaction. In order to determine the effectiveness of how mission operations are performed and to determine areas of improvement, measures of effectiveness (MoEs) should be identified. The metrics obtained through these measures of effectiveness can then be empirically and subjectively analyzed to determine the areas of the operation that should be improved or automated to increase efficiency.

For a science mission, effectiveness factors for the mission operations include:

- Percentage completion of science objectives (e.g., number of science experiments successfully executed, coverage obtained by imaging, quality of data, quality and quantity of calibration data obtained)
- Cost of operations (comparison of actual versus projected costs)
- Response time and flexibility of the mission planning an operations process
- Efficiency (cost/data collected)

Some metrics that can help measure the effectiveness of science mission operations include: error tracking, exceptions (complexity) factor, rush factor, effort factor, response factor, fatigue factor, and morale factor. These MoEs were first identified in post-mission analysis of the Clementine lunar mission and were very useful in determining where the mission operations process was successful and where it needed improvement. They were subsequently used in the analysis of other historical missions before being designed into a recently operational commercial mission operations system (Honeywell's DataLynx).

2.1 MoE #1: Error Tracking. This MoE tracks all the ground source errors that reach the spacecraft during the mission (although we are using the spacecraft as the end "victim" system, this MoE could be equally applied to other systems that receive external data that could cause errors in its execution). Most of the errors that reach the spacecraft are generated by the mission operations process or allowed to pass through it to the spacecraft. Spacecraft commanding and operations errors that affect accomplishment of mission goals may include:

- Planning and timeline/schedule errors – these are the errors introduced in the first steps of the mission operations process before actual commands are generated. For example, a timeline or schedule might direct that the spacecraft to go into a data dump mode before the tracking station is in view. The source of this error is usually human (the mission planner), but could also be a result of incorrect mission rules (requirements), an experiment design fault, or use of erroneous data, such as an out-of-date ephemeris.

- Command script/sequence errors – these are errors that are introduced after taking a timeline or schedule and turning it into a command sequence (although usually still in a human-readable rather than spacecraft readable form). The source of these errors is also usually human. They are especially likely to occur if a manual copy or cut and paste method is used to convert the timeline into a command script. This area is particular suited for automation or constraint checking.

- Instrument or spacecraft pointing errors – these are errors in determining or specifying the correct direction to point some apparatus on the spacecraft, whether an instrument, an antenna, or the spacecraft bus itself. The source of these errors is usually human or software. A pointing error can be introduced from the mission or experiment plan formulation phase all the way through the generation of the command script.

- Commands/script testing errors – many command scripts, after translation in the machine-readable form, are tested on a software simulator or a software/hardware testbed. Sometimes discrepancies between the planned command sequence as expressed on the timeline or script and the actually executed command script escape the notice of the testers, whether human or computer. However, sometimes command errors can even be introduced in this phase as "corrections" to the command script without full realization of the consequences of the changes. The testers might also have an erroneous configuration set up which does not match that which the command script will see on the spacecraft. This is one of the errors that resulted in the spin-up failure of the Clementine spacecraft that caused the loss of the asteroid encounter of the mission.

- Ground system errors – after the script has been tested it is passed along to the real-time or ground operations subsystem for delivery to the ground station for upload to the spacecraft. Errors can occur in this process (e.g, the wrong file is sent or at the wrong time). Included in the ground system errors are any errors that occur at the ground stations (hardware, software, and personnel errors). Hardware outages such as a transmitter or receiver failure at the ground station can affect the FOT's ability to send and collect data from the spacecraft.

- Real-time operations errors – any real-time commanding of the spacecraft during a pass or contact is prone to human errors, especially if constraint and command checking is not provided in the real-time commanding software.

- Spacecraft hardware errors – these are errors caused by faults in the onboard hardware of the spacecraft and are sometimes beyond the control of the ground operations personnel. However, many times problems with the onboard hardware can be resolved either by using workarounds or by making adjustments to the onboard system or configurations.

- Software errors (ground and flight) – this can be a major source of errors, especially in the initial phase of a mission before the system reaches a certain level of maturity. The "faster, better, cheaper" missions, because of their fast-track development cycle, are often launched before the ground or space software has been fully completed and tested. These missions often rely on a certain basic level of software to the basic essential operation of the spacecraft, but rely on software developed and tested during the mission itself for implementation of higher or more sophisticated functions. The use of software that is not fully developed and tested on an operational spacecraft can have dire consequences (e.g., the "spin-up" and effective loss of Clementine while testing some new asteroid encounter software—this was in conjunction with the testing error described earlier).

- Miscellaneous errors (communication links, ground segment hardware) – this is a catchall category of unlikely or rare sources of errors. If any of these elements become a significant source of errors (e.g., communication link), then it should probably tracked as a separate error. These errors can be either human or machine.

2.2 MoE #2: Complexity/Exceptions Factor. This MoE is a measure of the complexity of a mission "event" (e.g., pass, observation, or experiment). If there is a "standard" sequence for spacecraft operations, then this is the number of "exceptional" events being added to that sequence (e.g., special operations added to mapping). Metrics for this MoE are chosen to meaningfully reflect complexity (e.g., number of commands or activities required).

2.3 MoE #3: Rush Factor. This MoE is a measurement of time between timeline and/or script completion and script execution on spacecraft. The Rush Factor MoE is inversely proportional to the time, i.e., the less time, the higher the Rush Factor. Elements involved in the mission operations process that may affect the Rush Factor include time required for testing of scripts on simulator/testbeds and time required for queuing and upload to spacecraft. The Rush Factor should be low (days, not hours). However, in order to be responsive to the science team or customer in a dynamic mission, the Rush Factor may by necessity remain high, i.e., the higher the Rush Factor, the more responsive the operations team is although it is at a cost of putting strain on the team and processes.

2.4 MoE #4: Effort Factor. This MoE is a measurement of the number of man-hours expended per mission event. It can be measure of complexity, but it is complicated by the efficiency of the process as well as by the level of automation. The Effort Factor is desired to be low to reduce costs and possible sources of errors. Automation can reduce the Effort Factor (--for operations personnel, but increase it for software engineers and programmers--).

2.5 MoE #5: Response Factor. A trade study should be done to determine whether the decreased Effort Factor by operations personnel during the lifetime of a mission warrants the increased effort by the software developers to develop, implement, and test automation. Generally speaking, the larger the mission, the more worthwhile the software development effort will be. This MoE is an inverse function of the measurement of time between the customer's (e.g., science team) request for a mission event and its execution. The Response Factor should be weighted to account for complexity of the requested event. This factor should be maximized (i.e., the time between requests and execution minimized).

2.6 MoE #6: Fatigue Factor. This MoE is a measurement of the tiredness of the operations team (e.g., hours worked). The short-term Fatigue Factor is based on shift length, while the long-term Fatigue Factor is measured over weeks or months. Other factors (e.g., complexity, rush, effort, and response) can affect the Fatigue Factor. It may be determined by subjective data (e.g., questionnaires) and the number of errors generated.

2.7 MoE #7: Morale Factor. This MoE is a measurement of the satisfaction and optimism level of the operations team, but is difficult to quantify. It is mostly subjective, but some metrics can be collected to help in its determination. The possible metrics includes the turnover rate of personnel and the number operations personnel of complaints received by the operations management. It might also be possible to use routine surveys of operations personnel, but it has to be determined subjectively as to how accurately these surveys reflect the true morale of the personnel.

3.0 Metric Collection Process

In order to effectively generate, track, and use these MoE metrics, they should be incorporated into the mission operation process. Due to the limited record keeping typical in many of today's faster, cheaper, and better missions, it is often difficult if not impossible to reconstruct these metrics accurately, either to generate historical test cases or to determine retroactively how the MoE factors have changed over the life cycle of a current operations process. However, steps can be taken in the design of a new operations process or to implement changes in an existing system to collect these metrics.

At each step in the process two logs should be generated and kept. An automatic on-line log should record the time that each event starts and stops in a sub-process (e.g., recording the time that a timeline enters the script generation step and the time that generated script leaves this step to be sent on to the next step in the process, usually testing). This automatic log should also record errors detected by the computer system, especially of errors that were detected in the input data, as well as any significant decisions or substeps. A manual on-line electronic log should also be kept. This log is to record any errors found and corrected or changes made by the operator, along with the decision rationale. Both logs should be archived with the files for that particular pass or event and sent automatically to the operations director or analyst for review and analysis.

The following table shows possible measurement methods for each of the seven MoEs that have been identified in this paper.

MoE	Measurement Method
Error Tracking	Logs (automatic and manual) kept for each step in process to record any errors found and corrected
Complexity Factor	Determine from timelines/schedules
Rush Factor	Log the time of completion for each step in process Including execution on the spacecraft
Effort Factor	Log the time spent by each person on each mission event being processed
Response Factor	Determine from times in the log and the complexity rating of each mission event
Fatigue Factor	Determine from hours worked
Morale Factor	Use routine total quality surveys of personnel and note the turnover rate and the complaint rate

4.0 Metrics Analysis Process

The operations director or mission operations analyst should regularly collect and review metrics to identify problem areas. Trending software is of particular use to see how the factors change over time. The most useful plot is the cumulative errors plot, which shows on the same chart the cumulative total errors and each of the separate errors over the life of the mission or other designated time period. The cumulative number of errors is not so important, but the slope of the line is (i.e., the derivative of the cumulative errors with respect to time). By correlating the slopes of the line (steep slopes are bad, while flat or gentle slopes are good) to the seven MoE tracking charts, causes of the change in errors occurring on the spacecraft can often be identified by type. Steps can then be taken to analyze the details particular MoEs to determine the root cause of the problem (or conversely, the lack of problems that indicates something good was happening).

5.0 Feedback Implementation

Once a sub-process has been identified as needing improvement, total quality methods should be used to involve operations personnel in the solution. They can help in both the identification of the root cause of the problem as well as to help determine how to rectify it and work out a way to implement the solution into the operations process. Methods and metrics to determine the success of the implementation should also be identified. In some cases it might be necessary to include mission or program managers, and or customers (e.g., principal investigators or chief scientists).

6.0 Reporting Mechanism and Dissemination and Further Implementation

6.1 Any meetings involved in the operations process improvement process should be documented to leave a documentation trail of decisions made with rationale. This record is both important for historical purposes and to document decisions that might have to be reviewed at some later time, for instance, either to solve another similar problem, or (hopefully not) as evidence needed by a board of inquiry. Any reports or minutes of these meetings and decisions should be put into the operations archive and a copy sent to the mission manager or director, chief scientist, or other relevant entity.

6.2 MOEs can be very helpful in help to determine when and where to add automation to mission operations.

7.0 Discrepancy Tracking and Archive

As is true for other aspects of mission operations, all discrepancy tracking, metrics collection and analysis, problem resolution and decisions should be archived. Any feedback implementations that have been decided upon should be put into the formal discrepancy tracking system and followed by the operations director until the implementation has been fully completed and tested.

END

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GROUND SYSTEM DEVELOPMENT

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1.0 Introduction

This section describes Best Practices for ground system development, including both the development process and ground system design. Development process practices include such items as who should be involved, the reviews conducted during development, the design process, component selection, and component delivery, testing, and control. Ground system design guidelines include such items as on-line access to mission information and using TCP/IP communications, open and upgradeable systems, common hardware platforms throughout as much as possible, user configurable capabilities, and providing automation for monitoring and non-mission-critical control capabilities with robust paging capabilities. Much of this material originated from lessons learned identified by the EUVE team at UC Berkeley.

2.0 Development Process

2.1 Staff and Reviews

2.1.1 Operations staff/engineers should be involved early in the ground system design.

2.1.2 The ground system design team should include a mixture of those experienced in space operations ground systems and those with recent information technology training.

2.1.3 Require that system users, spacecraft engineers, ground system developers, and maintenance personnel work closely together in order to facilitate the development and maintenance process, minimize unnecessary delays, and ensure that the system meets user requirements and needs. Whenever possible, collocate mission team members.

2.1.4 Continued access to software developers (not just maintainers!) is critical for the rapid and reliable implementation of software enhancements or modifications.

2.1.5 Early internal project reviews are very important and beneficial. They allow for design changes, evaluation of the process and the team members, the suggestion of alternatives, and the identification of relevant drivers and risks. Conduct at least one thorough design review of the Control Center in order to achieve technical consensus and focus. Two such reviews are better: a preliminary one to review and critique the operations concept/plans and to raise relevant issues and concerns, and a final review to demonstrate satisfactory resolution of those same issues and concerns.

2.1.6 External reviews with independent review panels should also be conducted. For new missions, these should be conducted as subsystem design reviews coordinated with overall mission reviews, such as Functional Design Review, Preliminary Design Review and Critical Design Review. Review panels should be small and composed of people with directly related experience.

2.2 Design Process

2.2.1 Clearly define the intended users and customers for the ground system. Don't attempt to serve so diverse a set of customers that it is difficult to define consistent requirements. Categorize "needs" vs. "wants" and focus on the former first. Well-defined objectives and requirements are critical to successful development.

2.2.2 Early in the design phase promote extensibility by keeping as much generality of function in the design as possible.

2.2.3 Create common conventions for all interfaces: command, telemetry, etc.

2.2.4 Organize software applications into functional packages. This allows a modular design, which provides the flexibility of replaceable components.

2.2.5 Plan from the beginning for future system extensions as technology changes.

2.2.6 Always define the key interfaces for any system or subsystem before starting the implementation. Break down the large systems into subsystems with well-defined interfaces.

2.2.7 Build functionality into stateless libraries with strictly defined interfaces. This avoids duplication of code, simplifies maintenance, and reduces development and testing time.

2.2.8 Set up an infrastructure that will lend itself to adding automation. Introduce automation first that has been proven on other missions or does not involve mission safety.

2.3 Component Selection

2.3.1 Whenever possible, use commercial hardware. Make arrangements with vendors for quick supply of critical items, even for redundant systems. If you must use customized systems, obtain, in advance, spare parts to avoid work delays or system downtime during either development or operations.

2.3.2 Investigate and implement Commercial Off-The-Shelf (COTS) solutions wherever they meet program requirements, including such characteristics as reliability as well as functional and performance requirements. COTS applications are generally already operational, well documented, are easy to use, and come with some level of technical support (the more the better). These attributes may make COTS significantly cheaper to use in the long run, and easier to manage than in-house software development, albeit at the sacrifice of some level of flexibility. However, if a COTS evaluation determines that it does not meet all your requirements, the level of effort required to supplement it for full support of your operations must also be evaluated.

2.3.3 Avoid using languages and tools with a small user base that are not open source.

2.3.4 When possible, use "standard" languages (e.g., ANSI C, html) for portability purposes.

2.3.5 Always take the time to search the Internet for open source software that either does what's needed or can be easily modified. For example, UCB has made good use of non-UCB-developed freeware UNIX shell utilities.

2.4 Component Delivery, Testing, and Control

2.4.1 Maximize the use of Configuration Management (CM) and control mechanisms (e.g., via the UNIX MAKE and SCCS/RCS utilities) for source code, documentation, procedures, etc. All items should be under CM before testing begins.

2.4.2 Establish a well-defined software release mechanism, which will instill organization, control, and tracking, albeit at the cost of a little extra (value-added) bureaucratic overhead.

2.4.3 Make software releases distinct from software installations. The EUVE Project at UCB implemented this by developing the Flexible Software Installation (FSI), a UNIX-based freeware package.

2.4.4 Documentation should be in a standardized and portable format and be easily maintainable. The development and maintenance of WWW-based (e.g., html and text) documentation is relatively inexpensive, and greatly simplifies the cross training of personnel.

2.4.5 Use a problem or bug tracking system. Freeware packages exist (e.g., GNATS) that may be useful.

2.4.6 Recognize the importance of the spacecraft simulator in the timeline. It can be an important part of testing and training.

2.4.7 Consider the use of a "project definition" policy for all software development requests. Late in the EUVE mission UCB implemented this policy due to the continuous in-house requests for additional software tools. The policy required that all requests be formally written up and submitted for review. The small amount of extra-required overhead served to filter out unimportant requests, while ensuring that requests were clearly thought out in advance of submission for review. If approved, requests were then prioritized for development. This should be part of your CM process. (See paper on Configuration Management)

2.4.8 Allow for the testing of the ground system with the spacecraft as early as is prudently possible. These tests should evolve to the point that the actual operators and engineers are running operational procedures in a mission like environment using the ground system in all mission phases. This includes launch and ascent, activation and checkout, and normal operations procedures. If possible, continuous multi-day testing can expose unforeseen problems during the development process.

2.4.9 Consider phasing in any major changes (e.g., automation). Multiple phases not only allow people to adjust to incremental changes, but also allow for the implementation of the easy things first.

3.0 Ground System Design

3.1 General

3.1.1 Consider providing on-line organized access to all mission telemetry that makes it extremely easy and convenient to perform any on-demand science or engineering investigation. With today's computer technology, and the decreasing prices for storage media, this strategy may well provide an excellent return on investment in terms of data analysis and results.

3.1.2 Choose fast, reliable, flexible, open-ended, and proven data storage systems whose capacity can be upgraded to handle a great deal more data than the mission originally may envision.

3.1.3 Maximize the use of technologies like RAID that promote reliability and minimize downtime. Mission critical hardware and software (e.g. command servers) should have hot backups or other technologies that promote reliability and minimize downtime such as RAID (Redundant Array of Independent Disks). All ground systems should be configured to simplify backup procedures by using centralized data storage.

3.1.4 Use a highly integrated operating system that is reliable, powerful, flexible, and customizable. The EUVE team at Berkeley recommends Unix for these qualities, and its shell scripting capabilities alone have allowed all personnel—not only programmers—to implement incremental yet significant improvements across all areas of the EUVE Project. The downsides they experienced have been the need for better user training and the relative high expense of, and poor support for, UNIX versions of various common software applications.

3.1.5 Try to limit the number of computer hardware platform and operating systems in use (i.e., only one, if possible) in order to simplify and minimize network complexity and associated maintenance.

3.1.6 Missions which include data distribution among multiple locations should ensure that their networks can handle a great deal of Internet traffic. This is particularly important given the recent expansion in use of the WWW, and in the general migration for satellite operations and data transmission and delivery via the Internet. Pay close attention to NASA security and network bandwidth issues when purchasing routers and other network equipment.

3.1.7 Missions should use a common standard computer communications protocol. This will preclude the need for proprietary protocols and their associated hardware/ software and will greatly simplify system development, implementation, operation, and maintenance. The current ubiquity of TCP/IP makes it an obvious candidate for the near future.

3.1.8 The use of relational databases or object-oriented databases is extremely valuable for managing data such as command and telemetry definitions and long term engineering trending statistics. However, it is crucial that these databases be properly designed and implemented by a knowledgeable database programmer. If poorly implemented such databases can lead to major maintenance headaches and expenses. Also, database software will typically add overhead time to processes that use them.

3.1.9 Make maximal use of the WWW for any project requiring diverse geographic data distribution, as it can greatly simplify global communications. Its inherent ease of use and platform-independent nature make it an ideal means of on-line communications, and a great way to save money (e.g., paper, phone, and mailing costs). A local WWW server does, however, require some maintenance time, but this can be minimized if well managed (e.g., via the use of some up-front and consistent internal standards and controls).

3.1.10 Use programming languages and tools that are appropriate for the task at hand, and do not dictate the use of a particular language and/or tool without consideration for the specific task.

3.1.11 Provide user-configuration capabilities, including command line access. It is often convenient to temporarily modify the monitoring rule parameters (e.g., limit values) or to screen pages for expected conditions (e.g., non-standard payload configurations). This should be implemented within an overall configuration management structure that establishes rules for what can be changed under different levels of authority.

3.2 Automation

3.2.1 User interface tools for an automated system should be illiam on providing a means to determine the operations current status and to interrupt the automation when necessary. Automation does not need to provide routine display of all spacecraft telemetry, since the purpose of such a system is to replace manual monitoring. Such detailed displays can degrade overall system performance and require significant extra development and maintenance costs.

3.2.2 Automated telemetry monitoring system can be greatly simplified by not including capabilities to send commands to the spacecraft. Such immediate ground-based commanding has never been required for EUVE; on-board automated safety mechanisms (e.g., TMON/RTS or built-in safe modes) are typically used instead. The main focus of the system should be to detect anomalies and page someone who will then investigate and take corrective action. At this time this strategy is still much cheaper and more reliable than trying to build a smart system that can on its own diagnose problems and take corrective action.

3.2.3 Implement a method of persistent paging (i.e., at regular intervals) that requires an external acknowledgment to turn off. The EUVE Project at UCB uses multi-level paging – to primary (i.e., the EUVE ACE), secondary (i.e., select engineers), and “other” (i.e., everyone) groups – in order to ensure that pages are received by someone within a reasonable period of time.

3.2.4 The system should, preferentially, have some way to group together related problems for paging.

3.2.5 It is useful and recommended that there be a separate stand-alone system set up with the sole purpose of monitoring the primary telemetry monitoring system.

END

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PRE-LAUNCH SPACECRAFT OPERATIONS DEVELOPMENT AND TEST

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1.0 Introduction

This section describes Best Practices for the pre-launch spacecraft operations development and test process. A key risk mitigation for any mission is to:

Test the spacecraft and instruments as they will be operated and operate the spacecraft and instruments as they were tested.

Process practices include who should be involved, systems engineering, development management, personnel development, spacecraft integration and test support, and operations testing and training. The purpose of testing is to validate the systems, procedures, timelines, and personnel for flight operations. An effective means to prepare systems and personnel for flight is for the operations team to operate the spacecraft and instruments during integration and test.

2.0 Operations Development Management Process

Use an integrated team approach to mission design and operations development following good systems engineering practices.

2.1 Provide early feedback to the project, spacecraft manufacturer, and instrument teams concerning the impact of the spacecraft hardware & software design on meeting requirements for both ground test and flight operations. Where necessary provide recommendations for changes to design and/or requirements.

2.2 A review of the Operations Concept should be included as an integral part of all formal mission reviews beginning with the Systems Requirements Review, both at the system as well as the element level (e.g., spacecraft, instrument, ground).

2.3 Evolve the spacecraft / instrument design and the operations concept in parallel during the development phase.

2.4 Conduct thorough design reviews of the control center in order to achieve technical consensus and focus: a preliminary review to critique the operations concept/plans and to raise relevant issues and concerns, and a final review at which satisfactory resolution of those same issues and concerns is demonstrated.

2.5 Support the development of a spacecraft simulator for validating procedures, developing operations timelines, and supporting operations team training.

2.6 Working with the development team, prepare operations manuals and training materials which describe spacecraft and instrument systems, define the procedures for normal operation, identify processes for recognizing mission threatening conditions, and highlight the contingency responses to spacecraft and instrument anomalies. Document failure modes for each subsystem, event tables, Standard Operating Procedures (SOP), contingency procedures, and command scripts.

2.7 Conduct pre-launch meetings with spacecraft developer, subsystem discipline engineers, instrument team members, and Integration and Test (I&T) engineers to specifically define on a mission phase, subsystem, instrument, and special event basis what parameters are the most important to be monitored in real-time (on a spacecraft and instrument configuration / state basis) and what one should be looking for in those parameters.

3.0 <u>Operations Team Development Process</u>

Include the operations team and science team members early in the instrument design process.

3.1 Include the operations team in the science team discussions of mission changes and development of new procedures after launch.

3.2 Cross training and multiple job responsibilities is essential to low-cost operations. Operations engineers should be controllers, schedulers, and planners, as well as ground systems and operating systems experts.

3.3 If possible, include the operations team in I&T planning and implementation. Effective training can be achieved by using the operations team to operate the spacecraft and instruments during the I&T process.

3.4 Cross train personnel from integration and testing to support launch and early orbit operations. They can provide surge operations team staffing and helpful engineering support for launch and early orbital operations.

4.0 Operations Systems Usage

Ensure a stable operations development environment following good systems engineering practices.

4.1 Recognize and take advantage of the potential for cost savings from using common systems for flight operations and for integration and testing. The use of a common system could avoid software translations and transfers, decrease validation requirements, reduce risk and lower cost. Particular advantages can be found in using common command and control software environments. Early planning can allow the use of ground support equipment (GSE) developed to support integration and testing for operations support. I&T GSE can provide a quick, low-cost, and proven capability for monitoring instrument or spacecraft performance.

4.2 Plan to use pre-launch and testing phases as training opportunities. Ensure that design/testing knowledge is documented and passed on to operations team.

4.3 Ensure the flight and ground software is stable, under configuration control, well documented, and thoroughly tested well before launch.

4.4 Implement increasing levels of configuration control by development and/or mission phase as appropriate.

5.0 Spacecraft Test & Simulation Support

An effective means to prepare systems and personnel for flight is for the operations team to operate the spacecraft and instruments during integration and test.

5.1 Support spacecraft sensor verification tests to validate understanding of sensor geometry and performance.

5.2 Support ground system compatibility tests and verify telemetry conversion values.

5.3 Use the I&T process as an opportunity to test and verify all operations modes before launch. The exercise of flight procedures and timelines are excellent ways of verifying spacecraft capabilities.

5.4 Operations simulations are an excellent means for testing software and associated user interactions. Carefully specify and develop spacecraft and instrument simulators with the highest possible fidelity within program constraints. Include the ability to test anomaly response by using simulators to inject faults.

5.5 Conduct simulations of key orbit maneuvers, spacecraft modes, and contingency plans to verify software and procedures.

6.0 Operations Testing

The purpose of testing is to validate the systems, procedures, timelines, and personnel for flight operations.

6.1 Base integration and testing on operations plans and procedures. Combine the integration, testing, and operations test plans. Use operations procedures in the test environment and capture systems responses and behaviors during integration and testing. This will avoid duplicate tests and procedures and ensure that systems are tested as they will be used.

6.2 If possible, use the operations team to conduct tests with developers in support.

6.3 Combine as much as possible validation and readiness testing for flight operations with the integration and test of the ground and space elements.

6.4 Allow for the hands-on control of the spacecraft by the operations team as early as possible. For example, begin monitoring spacecraft telemetry during all powered integration and test activities as soon as the ground systems are capable of doing so.

6.5 Allow for the testing of the ground system with the spacecraft as early as is prudently possible.

6.6 An end-to-end system testing philosophy from the spacecraft to the science data processing software will ensure that delivered systems are robust and reliable, and that operations personnel are well trained in the usage of the system.

6.7 Use the flight data processing facility to process and archive data acquired during integration and testing and simulated activities.

6.8 During flight operations, test commands and procedures with simulators prior to use. This will validate the procedures and familiarize the operators with expected performance.

6.9 Use the operations team to perform pre-launch calibration tests, to process the test data into calibration parameters, to implement the calibrations in the telemetry database, and develop limit monitors and values. The familiarity with calibration procedures gained by the operations team will reduce risk for any on-orbit calibration activities. In addition, the knowledge gained about the contents of the telemetry will improve the operations team ability to respond to out-of-limits conditions.

6.10 Exercise limit monitoring in ground systems during integration and test activities to gain experience with out-of-limits conditions and responses.

6.11 Identify, define, and document those remaining spacecraft and / or instrument failures requiring time critical ground intervention and document clear and concise recovery procedures for each.

END

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LAUNCH AND EARLY OPERATIONS

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1.0 Introduction

The Launch and Early Operations (L&EO) phase is the most critical of all phases of a mission and usually lasts anywhere from a few days to several weeks. Typically, it involves the initial activation of a new spacecraft that has yet to be proven under all the rigors of space flight and a mission support team that is still working to become proficient at operating the spacecraft. In some cases the ground system being used may also be entirely new, or contain newly added capabilities and interfaces. In addition to a steep learning curve, there is usually significant pressure to complete activation of the spacecraft as soon as possible in order to ensure its safety and allow it to begin carrying out the mission it was designed to accomplish.

Because the L&EO phase is such a critical period, it warrants special consideration in terms of testing, training, and planning to ensure that: (a) capabilities and procedures developed for routine operations can meet the more exacting demands of this mission phase, and (b) once on orbit, all systems can be quickly and systematically checked out in order to complete the L&EO timeline according to schedule. With this in mind, the following list of best practices has been compiled under the three general headings of staffing, ground operations, and spacecraft operations.

2.0 Staffing

Key to handling the demands of the L&EO phase are a robust staffing and training plan that can produce an operations support staff of sufficient number and skill to handle both nominal and contingency situations. Specific best practices with respect to staffing during L&EO are as follows:

2.1 *Shift Activation*: For missions that require 24-hr support over an extended L&EO period, consider staffing shifts one or two days before launch to acclimate personnel to schedules (note: this may not be worthwhile for missions that can transition to day shift operations shortly after launch)

2.2 *Backup Personnel*: Identify backup experienced individuals from other projects and provide them with minimal training so that they can be called in to help in the event of an emergency or unexpected staff turnover or illness.

2.3 *Prime Shifts*: If possible, schedule all critical operations during a single prime shift when all key members of the operations team can be present. Also, whenever possible, maintain a consistent schedule, with critical operations occurring on 24-hour centers.

2.4 *Shift Composition*: Ensure that each shift is staffed with the right mix of expertise necessary to perform their required tasks. In particular, subsystem engineers should be available to monitor and advise on key events that affect their subsystems.

2.5 *Staff Size*: Obtain sufficient personnel on the operations team to allow for adequate time off (e.g. at least one day off a week for first two weeks). While personnel may be expected to support longer hours with fewer days off for a short period, it is usually not wise to baseline this, since delays and contingencies superimposed on such a baseline may make it difficult to resume a normal schedule, thereby stressing operations personnel and adding risk to the mission.

2.6 *Staff Logistics*: Consider the following ways of facilitating certain logistics for operations team personnel to allow them to focus on their roles and responsibilities during L&EO.

- Cater meals for the first few days after launch and during critical events.
- Arrange to have key personnel with long commutes to stay at near-by lodging for several days after launch. Also, it can be useful to have a number of cots on hand to allow operations personnel to get some rest during extended periods of contingency operations.
- Ensure the availability of conference rooms for meetings and problem resolution activities.
- Establish a detailed phone list for internal team members and external interfaces with home and office numbers.

- Create phone trees for personnel contact during contingencies and provide beepers to key personnel.
- For locations susceptible to inclement weather, identify individuals with 4-wheel drive vehicles that could be called into service to help team members commute to the operations center.

2.7 *Team Training*: Conduct rehearsals of the L&EO timeline from countdown through separation, capture, and other key events. Staff console positions/shifts and configure the control center precisely as they would be for actual launch support. Include external elements in such rehearsals (with actual personnel expected to support the mission, if possible) to familiarize them with the timeline and to exercise communication and data paths. Also, include contingency training as well as extended sims (e.g. 72-hr sims) to rehearse shift operations and stress the system under realistic support conditions.

3.0 Ground Operations

Ground operations best practices presented below address general ground system logistics and operations planning pertaining to the support of L&EO.

3.1 *Problem Resolution*: Resist the temptation to fix serious problems on the fly, as opposed to taking time out to think through robust solutions. Assign a person (e.g. systems engineer) pre-launch to be responsible for tracking and resolving contingencies. Use “Tiger Teams” to take involved problems off-line and allow the ops team to focus on immediate operation of the spacecraft (see Contingency Planning and Support Best Practices, Section 19).

3.2 *Chain of Command*: Establish before launch who needs to be involved in key decisions that may impact the mission, as well as the level of management approval and notification that such decisions will require. Ensure that access to such individuals is readily available to minimize delays to the decision making process.

3.3 *Voice Lines*:

- Establish separate designated voice lines to facilitate communication of information among key support elements and rehearse use of those lines during simulations (e.g., individual subsystem loops, mission director loop, launch loop, flight dynamics loop, ground station loop, etc.). Educate all team members on proper voice protocol.
- Allocate certain external phone lines in the control center for operations use only to ensure their availability for key events. Also, equip phone lines with speaker capability, conference calling and hands-free devices for communication with support elements as a back up to dedicated voice lines.
- Consider assigning a specific individual the task of answering phones during critical events to minimize disruption to operations.

3.4 *Command Philosophy*: Develop an appropriate commanding philosophy for each mission, and consider the tradeoffs between use of real-time commands vs. stored commands to step through the timeline. Rehearse the approach selected thoroughly before launch.

- R/T commanding provides more control over timeline and visibility into problems as they arise
- Stored commanding is more efficient

3.5 *Public Affairs*: Establish a public affairs outreach plan. Assign specific individuals to interact with the press to minimize interference with operations, and instruct staff to refer all press inquiries to the designated points of contact. Plan regular status briefings for the benefit of management and the press.

3.6 *Timeline*: Develop a detailed set of nominal and backup timelines. Build sufficient slack into the timeline to facilitate the handling of inevitable glitches, delays, and contingencies.

3.7 *Event Validation*: Include expected telemetry conditions in the timeline that can be used to confirm the successful completion of each event, and indicate alternative action in response to any failures.

3.8 *Security*: Ensure that security provisions are maintained throughout L&EO, with restricted access to operations areas. Develop a plan to manage VIP presence and control center traffic to avoid possible interference with operations.

3.9 *Control Center Configuration*: For control centers with distributed computing, perform loading tests under realistic conditions to ensure that software is efficiently allocated across platforms with acceptable performance during peak operations.

3.10 *Software Updates*: Maintain software personnel on station for the first few days of L&EO to handle emergency software changes, and plan for a post-launch software build.

3.11 *Cross-Shift Communication*: During the extremely active time of L&EO, it is essential to maintain good communication between all personnel on the team. To that end, the following steps may be helpful:

- Schedule formal shift handovers where spacecraft (e.g., health, configuration, anomalies) and operations (e.g., s/w and hardware configuration, telemetry processing, mission planning, timeline execution) status can be reviewed and objectives outlined for each shift.
- Maintain detailed logs of events and a bulletin/white board of key announcements
- If possible, establish a mission web site to facilitate access to information by team members from home. Up-to-date information available on such a web site can include phone lists, staff schedules, mission status and logs, telemetry data and

plots, and documentation (e.g., timelines, mission handbooks, reference material, etc.).
- Consider setting up a call-in phone message system to announce key information to operations personnel (e.g., launch status).
- Follow configuration control practices and mark up (or update) approved changes to key operations documents and ensure their distribution to affected personnel. In particular, approved redlines to the timeline should be delivered to the entire mission team prior to each shift/event.
- Develop an operations checklist that is tied to key timeline activities, and use this checklist to track accomplishments of required events/tasks. Such a checklist serves as a useful operational roadmap and provides a measure of overall mission status. It can be a valuable tool during shift turnovers.

4.0 Spacecraft Operations

This section provides some operations best practices concerning the launch, activation and maintenance of spacecraft during L&EO.

4.1 *Launch*: In the event of a launch delay, ensure that the actual launch time, and updates to the orbit, timeline, and pertinent mission planning data (e.g. contact times, shadow passage, etc.) are communicated to the entire mission team (e.g., including external elements like ground stations).

4.2 *Initial Acquisition*:

- The on-board sequence triggered by separation should initiate first contact, as opposed to relying on "turn-on" through ground command. This will help isolate problem sources (i.e., by eliminating the command link from consideration).
- Schedule as many ground station contacts as possible to handle initial spacecraft activation, health assessment, and possible L&EO contingencies. Also, for low Earth orbiting spacecraft, consider the use of TDRS for longer contacts during L&EO.
- Ensure that ground stations are well informed of L&EO mission activities (e.g., using network briefing messages), with particular emphasis on critical passes. Provide updates to ground stations on mission status, including changes to the timeline, spacecraft orbit, transponder frequency, etc.
- Review and provide input to nominal ground station acquisition plans and procedures for the first several contacts in order to establish familiarity with station procedures and better coordinate troubleshooting activities.
- Establish and rehearse backup procedures for failed acquisitions with ground stations, and develop a systematic plan for isolating communication problems to either the ground system or the spacecraft.

4.3 *Launch Vehicle Separation*: Arrange to receive a post-separation orbit and attitude state from the launch vehicle. Also arrange to receive NORAD tracking in the event of an anomaly.

4.4 *Power Management*: Ensure that nominal spacecraft deployment attitude and contingency modes provide sufficient power margin over an extended period of time (e.g. one day) in the event of a failure to acquire the spacecraft (e.g. if spacecraft transmitter is cycled on/off via a pre-programmed sequence, make sure this does not drain the battery under off-nominal conditions). Implement watchdog timers on-board as needed to turn critical hardware on/off in the event of stored command failures.

4.5 *Single Event Upsets*: Investigate the effect of Van Allen Belt (VAB) crossings (and to a lesser extent South Atlantic Anomaly crossings) on spacecraft performance, and avoid scheduling critical spacecraft events around such crossings until their effects are well understood.

4.6 *Checkout of Redundant Systems*:

- Carefully review which redundant systems need to undergo an on-orbit checkout. Plan to perform an early checkout of only critical redundant systems which could be switched to autonomously, and defer checkout of the other redundant systems (as necessary) to later, when more time is available.
- For autonomous systems that can fail-over in either direction between primary and backup units, consider the possibility of checking out the backup system first, before switching to the primary system and checking it out. Also while checking out a backup system, consider use of a “deadman” stored command sequence that will automatically return control to the primary system after a certain period of time. In the event of unexpected loss of communication with the spacecraft, this type of measure will minimize the time the spacecraft will continue to operate on an untested backup system.

4.7 *Recorder Downlink*: Consider more frequent dumps of recorded data early during the mission in order to permit timely review of recorded subsystem data, and to maintain recorder storage capacity in the event of a future problem.

4.8 *L&EO Contingency Planning:* Prepare and rehearse L&EO contingency plans for all critical events (e.g., failed initial acquisition, safe mode recovery, etc.).

END

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FLIGHT DYNAMICS

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1.0 Introduction

Flight Dynamics support consists of all analysis and operations necessary to determine and control the orbit and attitude of a spacecraft. Operations entail the generation of a number of products, including definitive orbit and attitude solutions, orbit and attitude predictions, event predictions (e.g. station contacts, eclipses, etc.), and orbit/attitude control system command data (e.g. orbit state vectors, star catalogs, sensor biases, maneuver times, etc.). Flight Dynamics analysis consists of a variety of pre/post-launch analysis topics involving orbit/attitude mission design and spacecraft maneuver planning. As Flight Dynamics functions are an important part of spacecraft operations, there should be close coordination between analysts performing these functions and Flight Operations Team (FOT) personnel who control the spacecraft. Consequently, it is often advantageous to perform as many of these capabilities as possible within the Control Center.

2.0 Requirements Analysis

Consistent with the general recommended best practice of involving the operations team early in the requirement definition process, Flight Dynamics personnel should take an active role in defining operations concepts and influencing mission design. Feedback should be provided to the project/science team concerning the impact of requirements on mission operations costs and risks, and recommendations provided on ways to minimize each.

2.1 *Pre-Launch Error Analysis*: Perform pre-launch error analysis to assess the ability of a proposed spacecraft sensor complement (e.g. attitude sensors, GPS, etc.) and processing algorithms to meet onboard attitude and orbit determination requirements.

2.2 *Orbit Data Requirements*: Establish tracking data requirements and orbit determination/prediction processing requirements necessary to achieve desired orbit accuracy.

2.3 *Cost Analysis*: Perform a cost analysis with regard to meeting project Flight Dynamics requirements and provide feedback on possible cost savings that could be achieved by relaxing tight accuracy requirements that necessitate intensive ground operations (e.g. post-processing of telemetry, in-flight sensor calibration, more frequent parameter uploads, etc.).

2.4 *Onboard Processing*: When possible, perform definitive attitude and orbit determination onboard to minimize operations costs.

2.5 *Product Delivery Schedules*: When possible, negotiate product delivery requirements that promote flexibility in terms of staffing (e.g. weekly deliveries vs. daily). Also, if possible, automate product delivery or make it available on the Internet for user access as needed.

2.6 *Orbit Maintenance Requirements*: When possible, negotiate orbit maintenance requirements that minimize the frequency of maneuvers (e.g. +/- 20-km altitude tolerance vs. +/-10 km). Re-evaluate and update orbit maintenance requirements as necessary throughout the vehicle life based on propellant remaining and changes in expected mission lifetime.

2.7 *Spacecraft Autonomy*: Where practical, recommend the use of autonomous spacecraft capabilities (e.g. momentum management, solar array slewing, initiation of contingency modes) in order to reduce operations life-cycle costs.

3.0 Spacecraft Design Evaluation

Provide early feedback to the project and spacecraft manufacturer concerning the impact of spacecraft hardware and software design on the ability to meet orbit/attitude operational requirements. Where necessary provide recommendations for changes to designs and/or requirements. As a rule, straightforward operations should always be a goal in designing a spacecraft. It is recognized, however, that in some cases tradeoffs may warrant more complicated operations in the interest of meeting difficult requirements and reducing spacecraft cost/complexity. In such cases, the project must be made aware of the operational impact and risk associated with these tradeoffs.

3.1 *Telemetry Parameters and Rates*: Verify adequacy of key attitude and orbit control telemetry data and rates for use in ground support of spacecraft (e.g. propulsion system temperatures/pressures and thruster history for orbit maneuver planning/calibration, attitude sensor data for calibration, etc.).

3.2 *Attitude Thruster Disturbances*: When possible, ensure attitude thruster firings occur in pairs with no net translational force imparted.

3.3 *Delayed Command Capability*: Ensure the ability to initiate key spacecraft events (e.g. orbit insertion maneuvers, attitude mode changes, etc.) via delayed command from memory.

3.4 *Thruster Sizing and Qualification*: Ensure that thrusters are properly sized such that maneuver duration and resolution are consistent with mission requirements. For a given propulsion system design, verify that thrusters are qualified to fire over the duration of all likely burns without heat soak-back or plume-impingement concerns (consider also contingency cases where longer burns might be required, e.g., a thruster failure requiring longer burns on remaining thrusters).

3.5 *Battery Sizing*: Verify that batteries can meet expected eclipse conditions throughout the transfer, nominal mission, and extended mission orbits.

3.6 *Solar Radiation Torque Profile*: When possible, ensure spacecraft surface symmetry relative to center-of-mass to minimize momentum buildup/dumping resulting from solar radiation torques.

4.0 Spacecraft Test and Simulation Support

It is crucial that operators take advantage of any opportunities to test their software directly with the spacecraft prior to launch. Whenever possible, manufacturer specifications on telemetry conversions, command functions, units, and spacecraft hardware configuration and performance should be verified (see Pre-Launch Spacecraft and Operations Development and Test Best Practice). This is particularly true for spacecraft hardware supported by Flight Dynamics functions. However, in addition to tests with the spacecraft, simulations should also be carried out to verify Flight Dynamics operations plans, procedures, and timelines. While it may be possible to rehearse certain capabilities (e.g. orbit maneuver design and product delivery) without the use of a high-fidelity spacecraft simulator, other Flight Dynamics capabilities (e.g., attitude determination, sensor calibration, orbit determination) do require sophisticated modeling of spacecraft sensors and orbit/attitude geometry for realistic simulations. High-fidelity simulators can also be very helpful in support of spacecraft operator training, particularly for spacecraft with complicated attitude maneuver profiles. Typically, orbit determination capabilities are exercised using generic (i.e. spacecraft-independent) simulators with access to simulated spacecraft trajectories.

4.1 *Sensor Alignment*: Support spacecraft attitude sensor alignment verification tests to validate understanding of sensor mounting geometry and polarity.

4.2 *Sensor Performance Characteristics*: Where possible, participate in spacecraft tests in order to collect data on sensor performance (e.g. gyro bias temperature sensitivity may be observed during thermal vacuum testing).

4.3 *Telemetry Conversion Values*: Support ground system compatibility tests and verify attitude/orbit telemetry conversion values supplied by spacecraft manufacturer.

4.4 *Engineering Units*: Verify the use of consistent units between spacecraft designers, software developers, and operations personnel.

4.5 *Simulations*: Conduct simulations of key orbit maneuvers, spacecraft attitude control modes, and contingency plans to verify software and procedures.

5.0 Mission Analysis

Perform the following mission analysis activities as required for each mission, making sure that project, systems engineering and affected subsystem personnel (e.g. attitude control, thermal, power) are aware of results.

5.1 *Launch Window Determination (time of day and day of year)*: Based on mission requirements and propellant budget constraints, establish the available size of the launch window.

5.2 Launch Vehicle Analysis

5.2.1 *Launch Vehicle Selection*: Provide recommendations to project on candidate launch vehicles that meet spacecraft mass and deployment orbit characteristics.

5.2.2 *Consistency Verification*: Verify consistency of coordinate systems, units, and trajectory modeling parameters with launch vehicle personnel through the use of test cases.

5.2.3 *Separation Vectors*: Establish requirements for the delivery of separation state vectors as needed.

5.2.4 *End to End Modeling*: Ensure that the launch vehicle provider assumes responsibility for modeling any transfer orbit injection stage when possible.

5.3 *Propellant Budget*: Ensure an adequate spacecraft propellant budget that can meet all expected maneuver requirements (including transfer orbit and mission orbit maintenance maneuvers, and attitude control thrusting) and dispersions (both launch vehicle and spacecraft propulsion system) with sufficient margin (e.g. 10%).

5.4 Propulsion System Modeling

5.4.1 *Blowdown Characteristics*: Obtain propulsion system "blowdown" characteristics (e.g. thrust vs. pressure and ISP vs. pressure curves) from manufacturer for maneuver planning.

5.4.2 *Maneuver Performance Modeling*: Account for the effect of attitude control thrusting on orbit maneuver performance (e.g. thruster off-pulsing during orbit maneuvers for attitude control).

5.4.3 *Orbit Disturbance Modeling*: Account for the effect of long-term attitude control thrusting on orbit evolution.

5.5 Spacecraft Launch Date and Deployment Orbit

5.5.1 *Launch Parameter Update Requirements*: Establish requirements for updates to launch vehicle and spacecraft parameters for each candidate launch date (e.g. injection state, injection stage ballast masses, pre-loaded separation or maneuver attitudes, etc.) and prepare data in advance.

5.5.2 *Launch Data Validation*: Generate required Flight Dynamics predicted products for all planned launch dates and across the entire launch window on each date to verify station schedules, shadow profiles, and sensor visibility/interference profiles.

5.5.3 *Performance Requirements*: Provide launch vehicle manufacturer with the nominal and three-sigma deployment orbit requirements.

5.5.4 *Dispersion Analysis*: Ensure that three-sigma deployment orbit altitude is sufficiently high that drag will not significantly impact the mission lifetime in the event of delays in spacecraft operational timelines.

5.5.5 *Risk Reduction*: Design deployment orbit and attitude geometry to minimize risk to the spacecraft in the event of delays in ground contact with the spacecraft. This includes a spacecraft deployment geometry with solar array orientation in a power-positive state and with antennas pointing in the direction of upcoming station contacts.

5.6 Transfer Orbit Design

5.6.1 *Maneuver Visibility*: When possible design maneuvers to occur in view of a ground station.

5.6.2 *Backup Station Coverage*: For key maneuvers (e.g. planetary orbit insertion) schedule backup station coverage if possible.

5.6.3 *Eclipse Analysis*: For geosynchronous and planetary transfer orbits, verify that transfer orbit does not unexpectedly pass through Earth shadow cone.

5.6.4 *Maneuver Modeling*: For large maneuvers, ensure that tracking data supplied to ground stations has maneuver Doppler characteristics modeled in order to prevent station from dropping lock.

5.6.5 *Station Selection*: For large maneuvers, consider using 26-meter stations with autotrack capability when link margins permit (i.e. within 0.01 AU of Earth) as a measure against dropping lock.

5.6.6 *Independent Verification*: Verify critical orbit maneuver planning conditions using independent software and/or personnel.

5.7 Mission Orbit Design and Maintenance Requirements.

5.7.1 *Mission Orbit Design*: Design mission orbits with minimum maintenance requirements for the given science objectives and launch capacity.

5.7.2 *Orbit Maintenance Requirements*: Negotiate orbit tolerances (e.g. on altitude, eccentricity, inclination, argument of periapsis and ascending node rotation) that maximize the time between maneuvers in order to minimize fuel use and operational risk (see Flight Dynamics Best Practice 2.6).

5.7.3 *Maneuver Scheduling*: When possible schedule maneuvers to occur early to mid-week to permit execution, validation and any contingency measures to be completed prior to the weekend (when internal/external supporting elements may be staffed down).

5.7.4 *Maneuver Database*: Maintain a database of maneuver and propellant conditions (maneuver date, pre/post maneuver orbit/attitude state, fuel remaining, thrusters in use, tank temperature/pressure, etc.) and update after each orbit/attitude maneuver.

5.7.5 *Maneuver Calibration*: Perform a calibration of the propulsion system performance following each orbit maneuver, and solve for thrust parameters to be used in the next burn (taking into account attitude offsets, tank pressures, temperatures, mass properties, thruster selection, etc.).

5.8 End-of-Life De-Orbit Requirements

5.8.1 *Propellant Reserves*: Ensure sufficient fuel reserves to meet de-orbit requirements.

5.8.2 *De-Orbit Planing*: Prepare a de-orbit plan prior to launch with re-entry conditions that minimize risk to life and property.

5.8.3 *De-Orbit Initiation Criteria*: Establish any control system failure criteria that should trigger de-orbit operations by control personnel.

5.9 *Orbit Determination and Acquisition Data Generation*: Develop an orbit determination and acquisition data generation plan for early mission and nominal mission support.

5.10 Contingency Planning

5.10.1 *Initiation Criteria*: Establish trigger points for entering into orbit/attitude contingency modes.

5.10.2 *Orbit Maneuver Contingencies*: Prepare orbit maneuver contingency plans that address, among others, …

- Failed thrusters
- Delayed burn
- Attitude errors
- Premature burn termination

5.10.3 *Attitude Maneuver Contingencies*: Prepare attitude maneuver contingency plans that address, among others, …

- Actuator failures (e.g. momentum wheel, thruster, etc.)
- Attitude sensor failure (e.g. gyro, sun/earth sensor, etc.)

5.11 *Attitude Sensor Calibration Plan*: Prepare an attitude sensor calibration plan, as dictated by accuracy requirements, for in-flight computation of sensor alignments and biases which can be commanded to the spacecraft (for improved onboard attitude determination/control), or used in ground software (to improve attitude knowledge).

END

SATELLITE MISSION OPERATIONS BEST PRACTICES
BEST PRACTICES WORKING GROUP
AIAA SPACE OPERATIONS AND SUPPORT TECHNICAL COMMITTEE

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REAL-TIME CONTROL OPERATIONS

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1.0 Introduction

Realtime operations can generally be grouped into two types: continuous and periodic. Examples of continuous operations include all geosynchronous communications satellites and the US Space Shuttle and the International Space Station Alpha. Telemetry is received continuously, and command capability is almost always present.

Periodic operations include Low Earth Orbit (LEO) and Mid-Earth Orbit (MEO) satellites and planetary probes. In these operations, the satellite may only be in view, or ground resources may only be available for a few minutes. These periods of access may occur every hour, once a week, or even less.

This section addresses concepts related to Real-time Control Operations in a Space Mission Control Center.

2.0 Prior to Event (contact, maneuver, reconfiguration, etc)

2.1 Review upcoming events with all personnel. Make sure everyone understands what to expect, what role they will play, and what actions will take place. Review possible contingencies, and the procedures to be used. Solicit questions and comments. This not only prepares the operations team, but also prepares you to take appropriate actions if needed. A written or electronic "pass plan" aids in preparing the team and can serve as a checklist during the pass. This "pass plan" typically lists all procedures and plans of what will be performed during the pass. During post-pass, this can be used as a reference guide of what was accomplished during the pass.

2.2 Define a Pre-pass Test, which should be run prior to every contact. This test should checkout as much of the uplink and downlink processes as possible (including hardware and software). Make sure that the commanding portion does not throw off "expected" counts such as sequence counters in CCSDS, Authentication Words, etc… Ideally, this test should be performed in a timeframe that would allow enough time for corrective actions prior to the pass if problems are encountered. It should be noted that the incorporation of automated systems should not preclude the ability to checkout and identify problem areas.

2.3 A "briefing message" should be prepared and shared with all flight and ground elements involved in the real-time pass weeks or days out. Information such as AOS/LOS times, downlink telemetry rates, expected quantity of down linked data, etc. should be shared just prior to the pass. Preliminary estimates should be shared as early as practical for all elements.

3.0 <u>Evaluation of Spacecraft Health & Status</u>

3.1 Don't rely on color coding alarms and being able to look at every parameter to determine alarm conditions. Use a single status display to sum up alarm status, by instrument, subsystem, or function. Consider using an audible alarm or paging system, which would give notification upon entrance and exit from alarmed state.

3.2 Use Top-level displays which can be used to assess overall health & status. Allow for more detailed analysis with other displays with more detailed information. In addition, the use of graphics to display high level telemetry such as gas gauges or switches are a more intuitive and user-friendly way of showing status.

3.3 Make use of "derived" or "pseudo" telemetry that can combine telemetry indications to make a higher-level status indicator.

3.4 Use a "head-up display" capability (through a projector onto a screen), or use a system which can distribute telemetry to multiple work stations. This allows multiple persons to be able to view Telemetry simultaneously, with distributed systems allowing each user to define specifically what he or she specifically wants to view. Use of a "head-up display" also allows multiple people to view what is currently being typed and/or executed from the master control terminal.

3.5 If possible, develop a Spacecraft attitude visualizer (for example, a stick figure of the S/C with axes illustrating the S/C attitude relative to sun, Earth, Ram, etc…). If such a tool exists from the Guidance and Control (or Attitude) group for their use in testing, have that application modified to work off S/C telemetry and available to an FOT controller/evaluator. For 3 axis stabilized S/C, this is a very valuable tool. In a related matter, for Earth orbiters which use various ground station assets, use of a ground track software tool such as STK can be very useful in determining where the spacecraft is located in its orbit and relative to particular orbit milestones. This tool should be visible from the operators console and/or on a head-up display if possible; so it could be within view for more personnel in the Control Center.

3.6 Use care when setting alarm limits (limit sensing). Remember the boy who cried wolf. People quickly become desensitized to alarms if they occur too often, or for no reason.

4.0 Anomaly Response/Reporting

4.1 If possible, develop an anomaly database and enter all anomalies into this database directly or at least electronically. This makes it easier to catalog and produce reports from and can be scanned easily for similar problems, perhaps denoting a trend.

4.2 Develop an anomaly reporting process (via electronic database and/or paper) to track anomaly resolution status and to document final response and closure.

4.3 Utilize a 2-person check on commands and procedures used in implementing contingency plans.

4.4 Maintain a document that lists what response is expected of the Control team when alarms are encountered as well as other pre-defined Contingencies (i.e. Contingency Plan Document). This document should address both spacecraft contingencies as well as ground system contingencies.

5.0 Shift Changeover

5.1 Maintain a daily log that records *all* activity of the FOT (A good rule to follow is: "If its not in the log, it didn't happen."). There are many ways to keep a log, from simple handwritten sheets kept in a binder, to a database that can be sorted and searched. A good hybrid method is to keep a handwritten log, which can be used to record events, draw pictures, even personal thoughts. Later, the material can be entered into a database, adding or subtracting text as needed to insure accuracy and protect the innocent. This electronic version can easily be made available on a network, with access security as needed, to keep remote team members up to date.

5.2 Use a handover procedure/guide to insure all information is given to oncoming shift. This should be a checklist only, with the daily log as the prime source of information.

6.0 Unattended Contact Operations

6.1 For unattended operations, employ a remote paging system which lists enough detail in order for the personnel receiving the notification to determine the criticality of the situation. Ideally, the paging system should have a response function (from the pager and/or the internet) in order to acknowledge that the alarm message has been received, and a paging hierarchy (i.e. if no response received after X amount of time, page the next person on the list).

6.2 At a minimum, paging should be implemented to alarm in the event of any failure detected by the automation which indicates a failure of any local system aliveness check, any check that the ground network is functioning properly, that the communications between elements are occurring on-schedule and as planned, and that the space system is healthy and functioning properly.

6.3 A special acknowledgement should be implemented which would cause the system to repage in a reasonable amount of time in order to cover the situation where someone receives a page which requires them to go to the control center to respond to the alarm. This repage would then notify others in the event that the original responder to the alarm didn't make it into the control center in a reasonable amount of time due to something beyond their control.

7.0 Implement a method for remote access to pertinent information regarding ground system and spacecraft status and state-of-health to allow for remote troubleshooting.

8.0 <u>Spacecraft Control</u>

8.1 Never send any commands from memory, always have the procedure open to the correct step and send the commands as listed in the procedure. Executable procedures which have been previously tested are ideal for ensuring the correct commands make it up to the spacecraft. These procedures also perform automatic command verification.

8.2 Always use 2-person command verification prior to sending any commands. If multiple geographic locations are involved with the TT&C of the spacecraft always announce the commands and wait for alternate location responsible for the activity to provide confirmation prior to sending them. If the command actions can be verified in telemetry then ask the alternate location to verify the telemetry too.

8.3 During spacecraft emergencies, if possible, have a dedicated 'note taker' to keep a running log account of what is happening in real-time. If possible, personnel should also be keeping their own logs. A single person can't record everything that goes on.

9.0 <u>Miscellaneous</u>

9.1 Have a current shift/daily activity plan in the control room so that everyone on shift knows what is planned/required during the shift.

9.2 Especially for missions where contact duration is time critical, install a countdown clock which will allow people to know how much time remains in a current contact and/or when the next contact or major activity will occur at a glance.

9.3 Implement a method by which a member of the FOT or Spacecraft Engineering Team can submit a request for action on an upcoming station contact which doesn't have to go through the normal planning process. This request should be documented, tested if possible, and approved by two people prior to implementation. The important thing is to get such a method in place. For example if a member of the Guidance and Control team wanted to dump some parameters which are not normally telemetered, you would not want to have to go through the entire planning and validation process to have that accomplished.

9.4 Where possible, maintain in a command database, telemetry that can be used to perform functional verification of that command's execution on-board. For example, for every relay, there should be a bit in telemetry associated with a telemetry mnemonic that indicates the state of the relay; whether it be on/off, open/close, enabled/disabled, etc… These telemetry mnemonics should be captured in the command database. If this information cannot be maintained in a database, then a cross-reference spreadsheet would be used as a substitute.

10. Things for the Operations Manager to Consider

10.1 Develop a culture that encourages everyone to get involved, ask questions. Make training scenarios as close as possible to foreseen situations. Especially practice the person-to-person communications interfaces. Leaders should listen to other members of the team, even if they're questioning the wisdom of a particular course of action. We all make mistakes, and responding to questions can bring to light options that may not have been considered. During contingencies, in the heat of the moment, it is easy to become fixated on a particular pathway to the problem. Members should be encouraged to proceed slowly and think about other possible causes. Leaders need to keep in mind that there could be alternative causes and or solutions. It is highly recommended to not do anything that hasn't been previously planned.

10.3 Before making any important or critical decision, consider what type of a response you'll get from a review board if something goes wrong. It might be helpful to consider yourself in front of a review board, justifying your decision. If your reasoning is sound, you'll probably be okay. For very critical decisions, consider discussing your reasons for such a decision with a manager or peer and solicit their feedback.

END

SATELLITE MISSION OPERATIONS BEST PRACTICES
BEST PRACTICES WORKING GROUP
AIAA SPACE OPERATIONS AND SUPPORT TECHINICAL COMMITTEE

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MULTI-MISSION SATELLITE OPERATIONS CENTER (MM SOC)

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October 30, 2001

1.0 Introduction

The Multi-Mission Satellite Operations Center (MM SOC) is a reality today for several DoD and commercial organizations that operate multiple satellite buses and payloads. These centers have been formed where common processes and systems can be used among varying satellites to save operations and engineering support costs relative to dedicated individual satellite control centers. When applied correctly, best practices in MM SOC operations should provide a blueprint for realizing more mission capability using fewer resources.

The success of the MM SOC, however, depends even more strongly on applying best practices and rigorous management methodologies than an individual mission SOC, where a small team's cohesion can offset shortfalls in process control. The MM SOC team size and mission diversity contributes significantly to the operational and managerial challenges. Adding to mission complexity, the MM SOC may also have to interface with different ground systems and antenna networks. Best practices for MM SOCs should focus on enabling these organizations to optimize mission success, providing low risk solutions for safe operations while also promoting cost efficiencies. With the days of growing budgets for space agencies largely over, organizations should increasingly apply best practices for successful consolidation of satellite and mission operations, to economize on ground systems and personnel.

2.0 Characteristics of a MM SOC

2.1 Characteristics by Definition

As defined here, a MM SOC is not a constellation control center, but flies multiple satellites with different buses and payloads, and in many cases, different orbits. The uniqueness of the MM SOC stems from how these operational differences are synthesized into a coherent operations concept to allow maximum efficiency of operations.

2.2 Inherent Characteristics

Inherent to the MM SOC characteristic is the notion of "one-stop shopping" for satellite operations. The MM SOC should be able to do it all, starting with pre-launch preparations and ending with satellite end-of-life mission termination and disposal operations. Because most MM SOCs have tight budgets, cost effectiveness and efficiency are essential. It may seem counterintuitive that a MM SOC seeks to do it all and do it cheaply. What allows this combination, however, is a flexible and responsive operations concept. MM SOC operations must be capable of evolving and adapting as new technology becomes available or as new mission requirements are identified.

MM SOCs should operate with reduced manning, using automation, where appropriate, and applying personnel resources properly as required to mitigate operational risk. Moreover, a keen understanding of multiple mission priorities is essential to successful MM SOC operations because simultaneous missions will compete for limited resources. With multiple purposes, mission management (the planning, scheduling, and deconfliction) of resources becomes even more critical for success. It is imperative, therefore, that a streamlined administrative process and structure and a well-defined Chain of Command (CoC) exist to enable responsive decision making at appropriate levels, helping to further mitigate risk in the MM SOC. Together, these inherent characteristics of the MM SOC provide robust operational capability with Research & Development (R&D) agility.

3.0 Best Practices for MM SOC Operations

Many Chapters of Best Practices apply to MM SOC operations. To some degree the MM SOC must use best practices in everything it does to accomplish more with less. In looking at MM SOC best practices, however, the focus should be on practices that are unique to the inherent characteristics of the MM SOC.

3.1 Operations Staff and Operational Procedures[1]

The MM SOC provides the foundations for a new paradigm in satellite operations where a “generalist” flies the satellite bus and “specialists” fly multiple satellite payloads, each performing independent functions. With satellite operations becoming more “active,” and some satellites performing multiple missions that require interrelated bus operations, a generalist operator will monitor bus functions and authorize specialists to independently command multiple autonomous mission payloads.

3.1.1 Operations Staff: Generalist versus Specialists

For cost efficiency, The MM SOC will typically employ “Generalists” for its 24/7 operations. The term generalist captures the operator’s level of expertise and experience. The generalist is knowledgeable to some degree about everything: multiple satellite buses and payloads, the ground systems, communications systems, mission planning process, orbital analysis basics, etc. In general, they operate in a well defined and proven “safe box” (see figure 1 below) that minimizes mission risk. Within this box they are trained on basic ground system troubleshooting, first level satellite anomaly identification, and pre-approved contingency actions. They are capable of following well-established, procedural checklists and executing troubleshooting procedures that provide guidance to finding solutions to pre-identified problems, including satellite contingencies. Moreover, they are trained to identify operational issues requiring special attention and call in the appropriate “Specialists” when needed.

Specialists provide more specific engineering support services (see Figure 1 below). Primarily working day shift, specialists are “on-call” 24/7 to provide specific additional expertise and experience when needed. Whether a ground systems expert or a Satellite Engineer, specialist labor is more expensive, and therefore, only employed after day shift hours “when needed” for either planned or contingency operations. The application of appropriate resources on an “as needed” basis enables the MM SOC to meet both risk mitigation and resource conservation goals.

3.1.2 Operational Procedures

Because of the use of generalists and specialist as noted above, operational procedures must be extremely well defined. These procedures delineate the “safe box” within which generalist operators are granted latitude to operate. The development of these procedures involves “operational administration,” or the process of smartly and efficiently developing, checking, and controlling operational checklists, troubleshooting guides, and contingency plans. These

[1] See also Best Practices Chapter on Operations Management.

may cover a broad spectrum of tasks, including operation of critical equipment needed to keep the SOC facility operating (AC unit, UPS system, etc.). The generalists will need to have detailed written instructions on how to perform basic mundane facility tasks as well as the complex satellite operations. For the development of these procedures, Subject Matter Experts (SME) work with generalist operators to build and refine workable processes to accomplish specific tasks and broad troubleshooting of complex systems.

Key to the development of these procedures is an assessment of risk on all operations to determine the boundaries of the "safe box". Some procedures contain little potential for risk while others may involve more complex operations that require extra precautions to ensure the health and safety of the satellite. The boundaries of the "safe box" are established through the use of well documented and proven Standard Operating Procedures (SOPs), Operational Checklists, Troubleshooting Guides, Contingency Plans, Flight Rules, and Support Classifications for various types of pass plans used in operations.

Flight Rules, for example, describe the hard and fast rules that limit flight characteristics for safe satellite operations that should never be violated, and provide appropriate immediate actions to safe the satellite for certain contingencies. They serve as a hard limit for both the generalist operations "safe box" and the specialist operations box.

The use of Support Classifications, on the other hand, exemplifies how the boundaries of the generalist operations "safe box" can be gracefully expanded to the larger operations box using specialists. Mission success is assured by having the greater expertise and experience of specialists immediately available for medium and higher risk operations. Supports can be classified according to risk levels such as in the following examples:

<u>Type 1 Supports:</u>

Definition: Non-critical Telemetry monitoring and/or Tracking supports.
Assessment of Risk: These are simple operations, passive to most satellite systems, and involve essentially no risk to the mission.
Operational Approach: Automate these supports; no operator required[2] since telemetry is automatically monitored by computer with pre-assigned limits that are updated and approved by a SME.
Examples: Automated Telemetry and Track Supports. Must have an acceptable support success rate, but the success of any individual support is not vital to mission success.

[2] No on console operator required. Depending on mission, operator presence may be required to respond to alarms and notify specialists, or an automated paging system might be used to recall different types of specialists based on different types of alarms.

Type 2 Supports:

Definition: Vital Telemetry monitoring and/or Tracking supports.
Assessment of Risk: These are simple operations, passive to most satellite systems, but completion is vital to some aspect of the mission.
Operational Approach: Only one generalist, operating both satellite and ground systems, is required. No specialist support required.
Examples: Non-automated Telemetry and Tracking Supports. Must ensure success of specific supports that are vital to mission success.

Type 3 Supports:

Definition: Simple Commanding supports.
Assessment of Risk: These are simple operations, and while not passive to most satellite systems, they involve low risk to the mission.
Operational Approach: Two generalist operators required, one to operate ground systems and one to operate satellite systems, no specialist support required. The operators are required to independently verify and concur on all commands sent to the satellite before those commands are executed.
Examples: Commanding supports to update non-critical payload data, dump memory buffers, or run redundancy checks on satellite hardware.

Type 4 Supports:

Definition: Complex Commanding supports.
Assessment of Risk: These complex operations are not passive to most satellite systems and involve medium risk to the mission.
Operational Approach: Two generalist operators required, one to operate ground systems and one to operate satellite systems, as well as a specialist to assist with commanding, telemetry analysis, and problem resolution (if necessary). The operators are required to independently verify and concur on all commands sent to the satellite before those commands are executed.
Examples: Commanding supports to update critical payload data, modify software configuration, or reconfigure satellite hardware.

Type 5 Supports:

Definition: Critical Complex Commanding supports.
Assessment of Risk: These are complex operations that contain high risk to the mission and must be performed at specific critical times.
Operational Approach: Two generalist operators required, one to operate ground systems and one to operate satellite systems, as well as two or more specialists to assist with commanding, telemetry analysis, and problem resolution (if necessary). The operators are required to independently verify and concur on all commands to the satellite before those commands are executed.
Examples: Commanding supports involving satellite maneuvers or anomaly recover actions.

The critical processes that affect operations must be well defined and managed. Errors introduced into the “safe box” of approved procedures increases mission risk. Therefore all critical processes must have Quality Assurance (QA) and Configuration Management (CM)[3] controls applied to them. Additionally, managerial supervision is essential to enforce the limits of the operational "Safe Box". Figure 1 illustrates how the Generalist Operations “Safe Box” fits into the larger Specialists Operations Box and what limits and controls are placed on these operating boxes.

Generalist Operations "Safe Box"

Allowable Operations:	**Limits of Generalist Box:**
Ground System Ops	Standard Operating Procedures
First Level Telemetry Monitoring	Operational Checklists
Basic Troubleshooting	Troubleshooting Guides
Basic Satellite Ops	Contigency Plans
First Level Contingency Procedures	Flight Rules
Mission Planning Scheduling	Support Classifications

Controls on Limits of Generalist "Safe Box":
Configuration Mangement (CM)
Quality Assurance (QA) Review
Management Supervision

Specialist Operations Box

Allowable Operations:	**Limits of Specialist Box:**
Advanced Satellite Ops	
Advanced Contingency and Recovery Procedures	On-Orbit Support Handbooks
Advanced Troubleshooting and Problem Diagnosis	Orbital Requirements Docuiments
Advanced Telemetry Monitoring	Engineering Specifications
Advanced Ground System Maintenance	Flight Rules
Mission Planning Requirements	Support Classifications

Controls on Limits of Specialist Box:
Advanced Technical Knowledge
Generalist "Safe Box" Controls

FIGURE 1: Operations Boxes for Specialists and Generalists

[3] See also Best Practices Chapter on Configuration Management for Satellite Operations.

3.2 Training[4]

The "classroom phase" of the training for both generalists and specialists first teaches the basics of each type of satellite bus and payload and all ground systems, including facilities. This basic knowledge should also include the fundamentals of how to operate in a real time environment (team skills) as well as what to operate. In other words, everyone who works in the satellite control room should be taught concepts of Crew Resource Management (CRM)[5], which include error management, communications, situational awareness, and workload management.

3.2.1 Generalist Training

The generalist requires, as a minimum, little prerequisite technical knowledge (obviously the more the better, but often little or none must suffice). The focus, after the basics are taught, is on procedures: ground system and satellite checklists, troubleshooting guides, and contingency plans. Ensuring that only the required material is taught in the classroom phase shortens the "training pipeline" and may allow the trainee to move quickly on to simulated operations within approximately four to six weeks.

It is important to move students to the "simulator phase" of training before putting them in a live operational environment. A simulator (that is capable of as high a degree of fidelity as is affordable) is necessary to allow the trainee to experience "on console" operations while "off-line." This enables the trainee to get familiar with the operational environment, practice procedures, and make mistakes without any mission risk. The training simulator should be capable of running anomaly drills that permit practice execution of critical contingency plans and reinforce CRM skills. The ability to "play back" telemetry and observe known anomalies provides excellent experience, building confidence and capabilities that operators will need when they face their first "live" anomalous condition. The simulator phase of training may take approximately four to six more weeks.

The next phase of the training cycle involves On-the-Job-Training (OJT). Once the generalist trainee is evaluated as "safe" in the training environment, they move into the SOC where they work as part of the watch team. Their qualifications are tracked by their progress in completing a comprehensive Personnel Qualification Standard (PQS). The PQS identifies required "knowledge" or "practical factor" skills that must be completed for each system or task. The trainee is assigned a mentor, who is a qualified shift supervisor, to help guide them through the qualification process. The trainee is at first closely monitored on each new task that is learned. Eventually the trainee is allowed to operate, without immediate supervision, systems that the

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[4] See also Best Practices Chapter on Training and Certification.

[5] For more information on the research behind CRM, see the University of Texas Human Factors Research Project web page at: http://homepage.psy.utexas.edu/homepage/group/HelmreichLAB/.

shift supervisor/mentor assess the trainee is capable of handling. Quantifying exact skill levels is very difficult, so shift supervisors/mentors must know their trainees capabilities well. At the same time, shift supervisors/mentors are granted a fair amount of latitude on how this training/mentoring proceeds. All members of the team, however, closely monitor the trainees' actions. Once the PQS is complete, the trainee is put through a series of "scenarios" to test knowledge and the ability to work through troubleshooting and contingencies. Finally a written test is given and, if passed, the trainee qualifies as a mission operator. The OJT phase of training may take approximately sixteen to twenty-four additional weeks.

Mission operators continue to receive individual training from the shift supervisor/mentor as progressively more complicated "scenarios" are completed each week. Upon the shift supervisor/mentor's recommendation, the mission operator will go to a shift supervisor "qualification board." This qualification board is comprised of shift supervisors and senior management who run the mission operator through the most complex scenarios. Mission operators will qualify as shift supervisors if they pass this board. The mission operator to shift supervisor phase of training may take approximately twenty to thirty additional weeks.

Fully qualified shift supervisors are required to pass annual re-qualification boards, similar to their final qualification board. Shift supervisors are also required to stay engaged in the mentoring of assigned trainees and mission operators.

3.2.2 Specialist Training

Specialists are educated mainly as satellite engineers or ground system technicians. For satellite operations, satellite engineers act as the specialists. For extensive ground system troubleshooting and problem diagnosis, ground system technicians act as specialists. This discussion focuses on satellite engineering specialists. These specialists act as part of the operations team for higher risk supports. They will attend a similar classroom and simulator phase of training as generalist operators, but they will be given more extensive and specialized training on satellite subsystems, telemetry analysis, and advanced operations such as maneuvers and anomaly contingency operations and procedures. It is essential that specialists spend additional time on the simulator, learning to recognize advanced system faults to become familiar with these possible anomalies. Additionally, it is crucial that specialists learn how to operate seamlessly as part of the operations team in a real time environment, employing CRM techniques, when necessary, to ensure mission success.

3.3 Automation

The goal is to automate as many functions as possible without risking the mission or breaking the budget. Automation is essential to the MM SOC in that it keeps down manpower costs by enabling fewer generalist operators to meet the majority of mission needs.

Some examples of successfully implemented automation efforts include the following:

- Automated Track Supports (ATS)[6]
- Automated Telemetry Monitoring[7]
- Automated Spacecraft Telemetry Trend Analysis
- Automated Mission Planning
- Automated Orbital Analysis[8]
- Automated Remote Ground Stations

Automated Telemetry Monitoring, for example, compares database values to incoming telemetry and sets off alarms to notify generalist operators when there is a disparity. The database table typically holds two high and two low values. The inner most values alert the generalist operator to note the out of limit conditions and then call in Engineering support to evaluate a new or changing trend. The outer values guard against a serious spacecraft condition and alert the generalist operator to notify Engineering support and take contingency actions, if appropriate. In this way, telemetry collection allows real time monitoring of satellite state of health 24/7 with a generalist performing this function. If a real time problem arises, a specialist can be quickly notified to address the anomalous condition. This telemetry data is collected and stored so that Engineer specialists can replay it to analyze trends during the day shift.

The net effect of automation for the MM SOC is that it reduces cost and conserves critical resources. By allowing the MM SOC to do more with less, automation acts as a "force multiplier" to accomplish tasks. Automation also relieves generalist operators to perform additional higher-level functions. Finally automation reduces human errors and improves mission success rates by reducing overall workload on generalist operators and eliminating the risk of operator error from repetitive but critical functions.

6 See Peter Blouke, Bernard H. Schwartze, and Brian Bayless' paper, "Lessons Learned from the Automated Use of the Air Force Satellite Control Network," presented at the International Space Development Conference, AIAA Technical Session, Houston, TX, May 1999

7 See also Best Practices Chapter on Single Screen Satellite Alarm Limit Display Requirements.

8 See Thaer A. Zori and Michael S. Mattis' paper, "Orbital Analysis Automation Initiative," presented at the Fourth International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operations at The Johns Hopkins University Applied Physics Laboratory, MD, April 2001

3.4 In-house Ground System Design, Development, Acquisitions & Testing[9]

Fundamental to the success of the MM SOC is the ability to rapidly change ground system technology to meet the ever-changing mission needs of the MM SOC and keep technology current with the latest available capabilities. The use of COTS hardware and software greatly enhances ground system development and flexibility. There is no such thing as a true "COTS" HW or SW solution for Satellite Operations, however. COTS ground system products must first be tailored for Satellite Operations and then further customized to meet the specific needs of the MM SOC. The implementation of these systems should focus on ease of operations as a primary goal. The ability to acquire, adapt, integrate, and test these systems in-house is also fundamental to the success of the MM SOC because it keeps cost down and is more responsive to the particular needs of the MM SOC. In-house control of the ground system is also essential to the MM SOC to give it the needed flexibility of operations to add and delete missions. Moreover, in-house ground systems management allows better integration of multiple mission ground system requirements into a single, common Graphical User Interface (GUI) for ease of generalist operations. Finally, in-house design, development, acquisitions, and testing enable operational input during all of these processes. Operators, engineers (both ground systems and satellite), orbital analysts, and mission planners must work together with developers and customers during the satellite acquisition process. With limited resources, a MM SOC has little capability to make up for poor ground system or satellite acquisition planning. Poor planning leads to manpower intensive operations.

3.4.1 Ground System Hardware and Software

The most important feature of the ground system from an operational standpoint is its GUI. For the MM SOC, with generalists performing day-to-day operations, the GUI needs to have a "common look and feel" across unique missions areas and satellites for simplicity and familiarity of operations. Unique mission requirements, however, should not be sacrificed to make the "common look and feel" conform in every detail.

Another feature that enhances the "common look and feel" is the use of common or standardized mnemonics across missions for similar functions and values. Proper application of this standardization allows minimal additional training on similar systems of different satellites.

The ground systems hardware and software should be modular in nature to facilitate upgrading various components by swapping out boxes or Mission Unique Software (MUS). Because the MM SOC must be adaptable, modularity is not optional. The idea of modular software is to keep a clean boundary of functions and processes between different modules of the software.

[9] See also Best Practices Chapter on Ground System Development.

For example, the foundation of MM SOC ground system software might consist of a Generic Operating System: essentially a COTS product. On top of this would reside the tailored Core Engine of the COTS ground system software. The Core Engine of the software should be targeted at the most essential mission of the MM SOC, in order to ensure that all functions of this priority mission can be most easily accomplished. On top of the COTS Core Engine, customized MUS, designed for each type of mission or spacecraft constellation, can be "plugged in" to the Core Engine. Each of these interfaces must be as well defined as possible with only essential connections between the various subsystems of the software. Plugged into the MUS are unique, individualized satellite databases. Modularity allows MUS to be added or removed with ease as new missions or constellations are added to the MM SOC's responsibilities. This modular design also limits regression testing when the software is upgraded to a newer version or is transitioned to a new hardware platform.

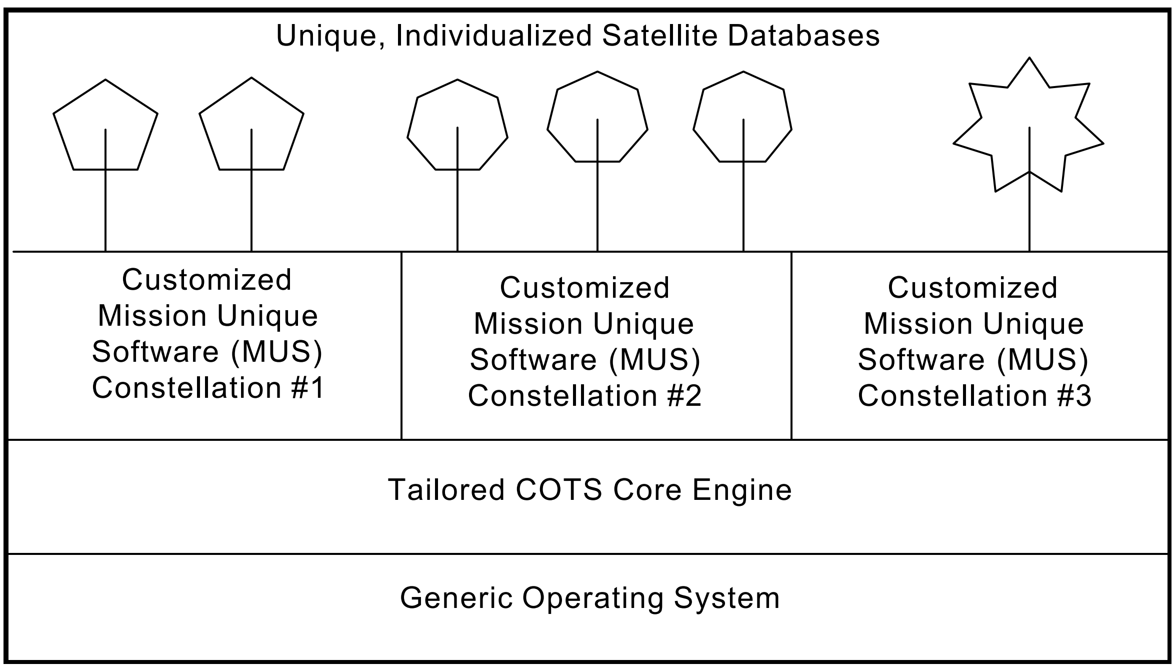

FIGURE 2: Modular Software Design Concept

3.4.2 Process Improvement Cycle[10]

Continuous process improvement is really only possible “in-house” since external organizations do not fully understand the specific needs, problems, and processes of the MM SOC. The ability of in-house personnel to recognize a problem and implement an internal efficiency review, or recommend a configuration change, is fundamental to the success of the MM SOC. This acts as a catalyst for the MM SOC to initiate an internal R&D cycle of its own current equipment and capabilities, consisting of Design and Development, Testing, Implementation and Parallel Operations, and Evaluation of new products. The ability of the operators to provide interface design feedback and use equipment that has “a common look & feel” also enhances operational success.

With the need for change being identified and acknowledged, MM SOC personnel will work with external vendors and internal support groups to innovate modifications or customized applications for existing systems and processes that can be built to meet new requirements. Proposed solutions are evaluated and, if acceptable, contracted and/or assigned to the appropriate external vendors and/or internal support groups. The new product is developed to meet the agreed specifications and then delivered for the Testing stage.

A prudent process of testing the product “off-line” must take place before it can be implemented in an operational environment. The off-line setting must mimic the operational environment in order to identify system deficiencies before they can have an operational impact. Moreover, an appropriate testing routine must be developed and approved to exercise the product under all normal operations and credible casualty scenarios. If a failure is detected during off-line testing, the product must be rejected until further modification resolves any anomalies in the off-line environment.

The Testing stage of product development also allows for creative experimentation to expand the utility of the product with easily achievable enhancements. This can lead to the product being returned to the Design and Development stage. An expanded test routine may need to be developed to cover expanded product capability when it is returned to the Testing stage.

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[10] This portion of the paper was adapted from Thaer A. Zori and Michael S. Mattis’ paper, “Orbital Analysis Automation Initiative,” presented at the Fourth International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operations at The Johns Hopkins University Applied Physics Laboratory, MD, April 2001. See also Best Practices Chapter on Process Improvement.

Unless testing is capable of unmasking even minor problems, the MM SOC is susceptible to substantial operational risk. This is successfully accomplished by creating a "cell" of testers whose job it is to prepare detailed test requirements and plans, and ensure that all testing is thorough and objective.

The next stage takes place in two phases. The first inserts the product into the operational environment, but provides for parallel operations with the old system or process still in place and being used/performed simultaneously. Again, an approved test routine must exercise the full range of operations and credible casualties. Parallel operations continue until the testing routine assures a satisfactory success rate with the new product. Failure of the new product at this stage stems primarily from an incomplete "off-line" model of the operational environment and these differences must be resolved before the product can be re-inserted into the actual operational environment. Often the failure is also partially due to inadequacies in the product. If this is the case, the product must be sent back to the Design and Development stage for additional modifications in addition to correcting the modeled operational environment. Phase one assures that operations are not impacted.

Phase two, removing the old system or process occurs once the new reliable product becomes available. This phase of implementation is essential since it scrubs operations of outmoded methods. Moreover, it allows true assessment of the new product within the integrated operations environment. The final stage, Evaluation, completes the cycle. With the goal of continuous improvement, this stage directs attention toward new technologies and operational techniques that can further improve systems and processes. Further efficiency reviews or changes to the configuration can then be considered. Figure 3 illustrated this cycle.

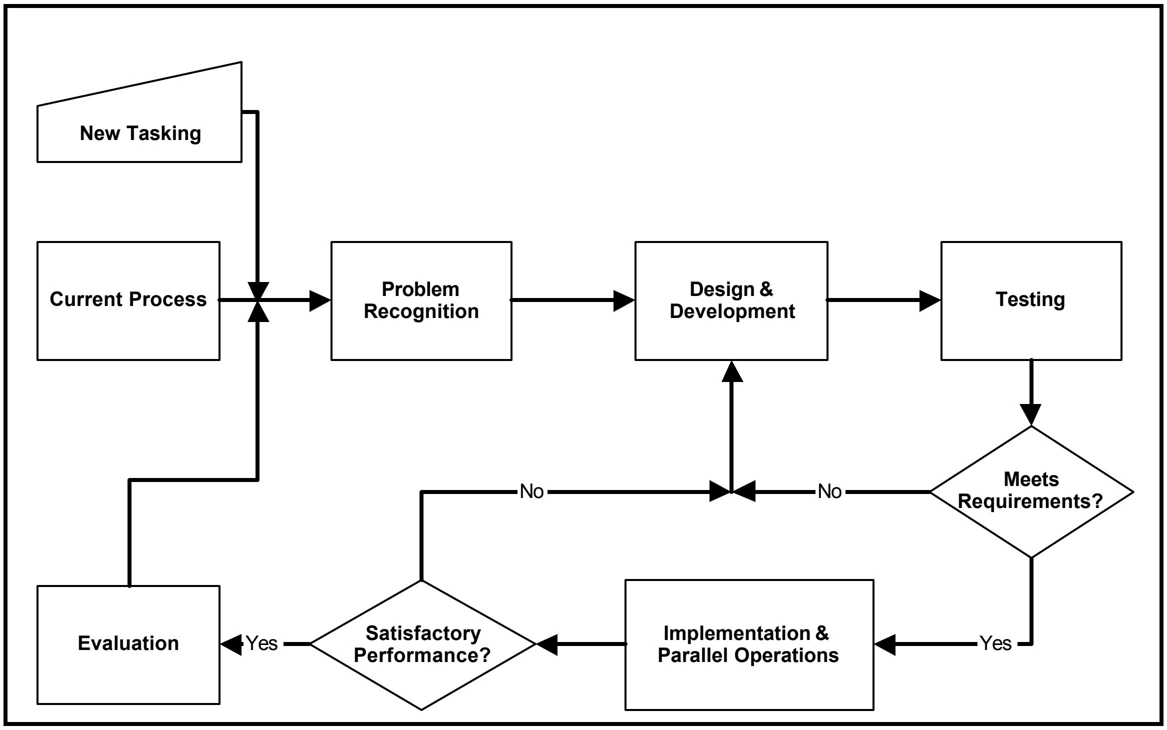

FIGURE 3. MM SOC Process Improvement Cycle

4.0 Conclusion

The MM SOC offers a unique capability to simultaneously support many diverse missions with high operational success and low cost. In this regard, the MM SOC is more than just an operational entity that should employ Best Practices; it is itself a Best Practice. The ability to mix operations with R&D, to perform in-house configuration changes in a relatively short period of time, and to have operational feedback in ground systems hardware and software, all enable the MM SOC to be a Best Practice. The appropriate use of generalist and specialist labor balance cost and mission risk. Automation enables amplification of cost savings and risk mitigation benefits. The major disadvantage of the MM SOC, however, is that the margin for error is often small. Process controls and decisive management must closely monitor and control the MM SOC operations to ensure that implemented cost saving techniques yield anticipated results without excessive risk to the mission.

END

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OFF-LINE SPACECRAFT PERFORMANCE ASSESSMENT

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April 13, 2001

NOTE: This also contains Real-time Monitoring Best Practices in some areas.

NOTE: Housekeeping telemetry refers mostly to that which is not science related; particularly things pertaining to health and status of the Spacecraft subsystems and instruments. This includes currents, temperatures, voltages, pressures, configuration telltales, attitude information, etc.

1.0 Introduction to Off-line Spacecraft Performance Assessment Section

Off-line Spacecraft Performance Assessment refers to the state of health monitoring, performance evaluation, and long term trending done outside of real-time satellite contacts with the ground station. It also includes the detection of anomalous behavior, which may have occurred outside of a real-time contact. Some aspects of real-time control are included here because of their applications in the off-line assessment environment. This section includes a list of practices that have been applied in the past in constructing an off-line spacecraft performance assessment system. The Best Practices described are based on a system that has been demonstrated to work very efficiently with a small number of staff members on a highly complex satellite.

2.0 Maintain on-line Archive of all Raw Housekeeping

Keep all spacecraft and instrument (if necessary) housekeeping data in raw format - on-line for easy access - for the entire mission, if possible. With the latest data storage technologies available, it is not as expensive as you would think. Make an approximation of how much housekeeping telemetry there will be; based on your data rates and the duration of the mission. Then add some margin to determine your storage requirements. One caveat may be that you are limited by budget constraints that may restrict you from maintaining all of the housekeeping on-line. In this case, try storing older data off-line; however, ensure that there is accessibility to this data, obviously making the retrieval as quick as possible.

3.0 Maintain a Critical Housekeeping Telemetry Data Base

Keep a critical subset of the housekeeping telemetry processed and stored in engineering units in a separate database so that you can perform ad-hoc queries of this data. Have several of these databases if necessary so as to include everything you feel you may like to run queries on. This capability is useful in anomaly investigations when trying to correlate several occurrences of the same situation. This also provides the ability to quickly respond to sponsor requests of "… what is the monthly average number of stars identified by the star tracker?" Or to a request by the Power Subsystem Engineer of "…how many times the Battery Depth of Discharge went below 50%?" Without having this type of database, in order to gather this type of information you would need to process a significant amount of raw data and perform manual searches, unless it could be imported into a relational database allowing queries. In any event, not maintaining this type of database capability greatly increases the amount of time involved in gathering this type of information.

4.0 Output Data in ASCII Text

The software tool used to extract and process the data into engineering units should output the data in ASCII text format. From there it can be easily imported to many different types of commercially available plotting packages including MS Excel, Pvwave, DaDisp, Matlab, etc. as well as a text editor. However, it should be kept in mind that large amount of data in ASCII format may cause the file to be extremely large and potentially unwieldy to move around. In these cases, it may prove more prudent to output and store the data in binary format. The majority of off-the-shelf packages, including those above, support binary format as well.

5.0 Compute Statistical Data

Ensure that the software, which processes the data into engineering units, is able to compute statistics such as min, max, average, and orbital average. Additional capabilities should include a Fast-Fourier Transform function and moving averages (such as one week, two-month, etc…).

6.0 Routine Plotting/Trending Recommendations

6.1 Generate and Output Plots Autonomously. The system should do this on a routine basis and at a convenient time for the assessment team to review them as you attempt to get them the latest and greatest data for reviewing. Other trending data products should be produced in a consistent format on a regular basis. The capability should exist for multiple X-axes. This allows an analyst to overlay a previous period with a current period to identify similarities and differences between the sets (see section 7.1).

6.2 Data Sets and Products. These should be defined for short (orbit by orbit, daily, weekly) and long term (several months to years) trending. The data sets and products should be updated, as necessary, as the spacecraft configuration changes due to failures, etc.

6.3 Trending Data. Ensure they are reviewed, analyzed, and found acceptable by knowledgeable individuals (preferably subsystem / instrument engineers) and/or key members of the FOT. If the data is reviewed by the FOT only, they need the knowledge to know when there is a problem. If possible, including nominal trending plots as reference for FOT members may help them notice when a problem arises.

6.4 Unexpected Trending Results. These should be further analyzed, with potential impact evaluated across the full operations team, and procedures updated to reflect required operations changes to track future conditions relating to the unexpected results.

6.5 Ensure That Results are Analyzed. This is necessary for potential incorporation into other operational missions and / or development missions to lower risk and aid in reliability engineering.

6.6 Have Different Frequencies of Trending. The capability should exist to generate plots at different frequencies depending on the parameter being trended to allow both short and long term trending. Have plots come out daily, weekly, monthly, quarterly, annual, and/or other rates depending on the frequency at which you would need to see these parameters. For example, you may want to see the solar array current for a time period that is synchronized to the orbit precession rate so that you see a complete cycle. It is common practice that you have the same plots come out at various frequencies so that you can see it at different resolutions and for recognizing short term and long term trends.

6.7 Real-Time Plotting Capability. The capability should exist to provide real-time plotting of telemetry for use during Real-time contact with the spacecraft. This tool should also be available for use off-line in replaying old telemetry.

6.8 Ability to Plot X-axis Other Than Time. The capability should exist to allow correlation between two parameters as opposed to just time. This allows, for example, correlating a thermal parameter with a portion of the orbit, or a particular spacecraft axis relative to the sun.

7.0 Multiple Axis Plotting Capabilities

7.1 Multiple Y-axis Plotting Capability. The capability should exist to create plots with multiple y-axes. Up to three is a minimum. This allows you to plot related items on the same plot so that you can see the relationships more easily. For example, battery depth of discharge and battery pressure should track pretty closely for a nickel-hydrogen battery. With them on the same plot, you can see how well they do track and can develop a substitute method of trending should one of the sensors fail.

7.2 Multiple X-axis Plotting Capability. The capability should exist for multiple X-axes. This allows an analyst to overlay a previous period with a current period to identify similarities and differences between the sets. This alleviates the need of holding the two pages back-to-back up to a light.

7.3 Make Any Parameter Easily Interpretable. The capability should exist to display any parameter that is uplinked and/or downlinked from the spacecraft in a format that is human readable, i.e. converted to engineering unit. This is to avoid the need for bit busting. At a minimum, the raw must be output as well to check the engineering units' conversion, but it is much easier and understandable for the MOT if they can interpret it quickly. This especially includes parameters loaded and dumped as data structures. These types of things are not routinely loaded or dumped, but when they are it is likely a critical time period.

7.4 Ad Hoc Plotting Capability. Ensure the system allows the user to plot parameters that are not otherwise routinely plotted. This is useful in anomaly investigation and resolution.

7.5 Evaluate Commercially Available Plotting Packages. PvWave has been used at Applied Physics Laboratory (APL), along with DaDisp. Ensure they meet your requirements. APL has also generated its own plotting tools. These were written in C and Visual Basic.

8.0 Telemetry

8.1 Engineering Telemetry Remote Access. The capability should exist to perform an automated transfer of routine "engineering files" to an unclassified server, where members of the MOT and engineering staff could log-on and download telemetry for their use in off-site (or at their desk) debugging of anomalies or routine performance assessment. Ensure the engineering team defines what data they most likely will need in the "engineering files".

8.2 Derived Telemetry Parameters. These are also referred to as "pseudo-telemetry." The capability should exist to combine parameter comparisons in defining a higher, better-defined state. You could conceivably "derive" a Spacecraft Top Level Health parameter, which if all its sub-parameters were considered "green", would indicate that the entire health of the spacecraft is "green". This capability should also exist in the Real-time environment. Whether this capability is accomplished through a rule-based system or an Object Oriented (OO) design depends on the application and those performing the implementation and maintenance. The "OO" approach is easier to maintain.

9.0 <u>Alarm Processing</u>

9.1 Clear Description of Each Key Parameter. A clear description and the significance of its data readings and trends are required. Limits or "alarms" should be assigned to each key parameter with specific instructions provided for MOT handling of out-of-limit or "alarm" occurrences. This should also be a real-time requirement.

9.2 Alarm Dependencies. Require that the "alarm" software allow for dependencies of other parameters being in a specific "mode" or "state". This allows the "alarm" to be more specific to a particular condition. This processing should also occur in the Real-time environment. The ability should exist to change these or add to them as the spacecraft evolves.

9.3 Alarm Trigger Count. Require that the "alarm" software allow for a "trigger count" where the condition must exist for a specified number of samples before it will actually signal the alarm. This processing should also occur in the Real-time environment.

9.4 Process "Alarms" for Data Recorded On-Board. Require that the "alarm" software used in the Real-time environment to be able to be run on the on-board recorded telemetry after it is downlinked. This allows for alarm checking of telemetry outside station contacts. Try to make it as quick as possible to expedite the process. This process should output a summary report of the alarms encountered during the span of the data analyzed by the alarm processing.

9.5 Prioritized Alarm Processing. In cases of simultaneous alarms, ensure all alarms may be easily detected, interpreted, and prioritized. In future Miss Operations Centers where “light-out” operations becomes more of the norm, this functionality will be more critical as the “system” will need to be able to prioritize alarms to determine the appropriate response.

10.0 <u>Reports Maintenance</u>

10.1 Spacecraft Configuration Change Log. Maintain a database or just a text file of Spacecraft Configuration changes. Include information such as the date and time of uplink or execution of the change. An example of this type of change may include the changing of the Battery Charge/Discharge ratio, or the reaction wheel gains, etc… This allows you to go back and make a correlation between a change and other effects, which may not be noticeable for several weeks. This is also a good thing to include in a summary of Events or a Sponsor Status report.

10.2 Maintain a Database of Anomalies. It is highly critical that the system maintains a database of anomaly reports that include a description and the resolution. This saves time in correlating similar problems and leads to quicker resolutions of subsequent occurrences. Create a standard naming convention such that ad hoc queries of similar problems is possible. In the DOD world, the complications of classification should be considered in the maintenance of an anomaly database.

10.3 Relay Information Back to The Spacecraft Manufacturer. Performance information and Lessons Learned from applications should be transferred back to the manufacturer for their information and assistance in improving their products and functions.

10.4 Periodic Assessment Reports. Periodic reports should be generated that discusses the trending analysis and highlight any areas of potential concern. These should be reviewed by a senior member of the technical or system engineering staff, with appropriate feedback provided to the FOT.

10.5 Plots embedded in E-reports. In posting Performance Assessment reports on servers or other electronic media, plots are better than columns of numbers to convey more information. One method is to embed plots in the ASCII text reports as encapsulated post-script. This will require that anyone printing the report need a post-script printer for the plots to come out in a readable fashion; however, it can add significant detail to the report for those who have such a printer. More modern methods include placing the plot on the Web in HTML format. ASCII reports are more desirable from a historical perspective because you will always be able to access this type of format.

END

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SINGLE SCREEN SATELLITE ALARM LIMIT DISPLAY REQUIREMENTS

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July 25, 2000

1.0 Introduction

COBRA currently displays alarms as a color change in the mnemonic/value pair. This type of alarm display system only displays the fact that a telemetry parameter is out-of-limits and an operator can only view the alarm condition by being on the telemetry screen that displays the telemetry parameter. In order to ensure an alarm condition is observed, the operator must be on the telemetry screen at the time the telemetry point is out-of-limits. Operationally this means an operator must go from screen-to-screen and/or a hierarchical drill down display process must be created.

Another method of displaying alarms is to create a screen, or display process, where all parameters that are out-of-limits are displayed on a single screen. This display process displays several pieces of information about an alarm event and displays several alarm occurrences on a single display. In addition, a single screen is used for all alarm processing for all supports in the Control Center. There are many advantages to this type of alarm display; the operator is notified as an alarm occurs, the operator gets a chronological list of the alarms, several critical pieces of information about an alarm condition are displayed in one place and multiple alarm instances are displayed only once. Another advantage is that the operator can immediately associate, or disassociate, a set of alarms with a particular event. By determining when a set of alarms occurred with respect to the time of an event, it is easy to determine in real-time whether the alarms are associated with an event.

The single screen concept lends itself towards automation because the operator does not need to be physically up on the support to “monitor” alarms. A process runs continuously that monitors the data flow in the control system (or the data is broadcast and picked up by this process). If an alarm condition occurs it is displayed on the alarm screen (or terminal). The system will display alarms from any pass and from any satellite controlled by the Control Center.

2.0 Requirements

2.1 Parameter Display List. The following is a list of parameters that should be available (with parameter plots if practical) for display on the satellite alarm display.

2.1.1 Parameter mnemonic and value.

2.1.1.1 Display parameter value at time of first occurrence.

2.1.2 Time of first alarm occurrence.

2.1.2.1 Display time actual alarm occurred.

2.1.3 Number of alarm occurrences.

2.1.3.1 See filtering below.

2.1.4 Value of limit.

2.1.4.1 Display the value of the alarm limit that was exceeded.

2.1.5 Support Identification Information.

2.1.5.1 Display support identification.

2.2 Display and Print Field.

2.2.1 The display and print field should be in landscape layout (or selectable by user).

2.2.2 The display and print field should allow for at least 15 (20 preferable) alarm instances on one screen or one page.

2.2.3 A print function shall allow printing of all alarms in the queue, even alarms not on the screen.

2.2.4 Alarms will be displayed from top to bottom with the most recent alarm on the bottom.

2.2.5 The alarms will be displayed until deleted from the display.

2.2.6 Alarm data will be recorded.

2.2.7 A method should be employed so the user can view all of the alarm conditions even if the display field is full, for example a scrolling screen or another alarm page or window.

2.3 Filtering. It is not operationally useful to display each occurrence of an alarm when a telemetry parameter is dithering in and out-of-limits. The preferred method of displaying this information is to display the alarm condition once, and then display the number of times the alarm occurred. Filtering specifies exactly under what conditions a new alarm field is generated for a dithering telemetry value and further enhances displayed alarm information. Specific requirements for filtering follows:

2.3.1 Number of Alarm Occurrences.

2.3.1.1 This parameter displays the number of times a telemetry parameter dithers in- and out-of-limits, subject to the filtering parameters discussed below.

2.3.2 Filter Parameter 1.

2.3.2.1 This parameter, set by the user, is a time limit within which alarm occurrences are filtered.

2.3.2.2 This parameter should have a minimum range of 10 – 10,000 seconds.

2.3.3 Filtering 1.

2.3.3.1 The alarms are filtered by time between occurrences.

2.3.3.2 Any instance of a specific alarm that occurs within the filter parameter increases the “Number of Alarm Occurrences” for that telemetry parameter.

2.3.3.3 Once an alarm occurs outside of the filter parameter, the filter parameter is reset. A subsequent alarm condition would then be displayed separately.

2.3.4 Filter Parameter 2.

2.3.4.1 This parameter, set by the user, is based on the number of decimal counts of the telemetry parameter over or under the limit threshold.

2.3.4.2 The parameter should have a minimum range of 0 – 255 counts.

2.3.5 Filtering 2.

2.3.5.1 The alarms are filtered by a value whose level is set by the value of the initial alarm condition and whose range is determined by filter parameter 2.

2.3.5.2 Any instance of a specific alarm condition that occurs within the range of counts set by filter parameter 2 increases the "Number of Alarm Occurrences" for that telemetry parameter.

2.3.5.3 A subsequent alarm condition that occurs outside of the range of counts determined by the first alarm condition is displayed separately. This new alarm condition sets a new level, but not a new range, for filter parameter 2.

2.3.6 Filtering 1 and 2 should be compatible with each other.

2.4 Single Screen Requirement.

2.4.1 The single screen concept would probably require a continuously running process. All support alarm data is fed to a single screen (or terminal) that is centrally located in the operations room. The single alarm screen picks up all alarm data, regardless of support or satellite.

END